

**COMPOSTING AS A BEST MANAGEMENT PRACTICE  
FOR REDUCING THE IMPACT OF FISH WASTES FROM  
MARINAS AND PROCESSING PLANTS ON GROUND  
AND SURFACE WATERS**

**FINAL PROJECT REPORT**

**SUBMITTED TO THE  
LOUISIANA DEPARTMENT OF ENVIRONMENTAL QUALITY**

**by**

**Dr. Thomas B. Lawson  
Department of Biological & Agricultural Engineering  
Louisiana Agricultural Experiment Station**

**Dr. Gary Breitenbeck  
Agronomy Department  
Louisiana Agricultural Experiment Station**

**And**

**Dr. Billy Cochran, Environmental Education  
Louisiana Cooperative Extension Service**

**Louisiana State University Agricultural Center  
Baton Rouge, Louisiana**

**February 20, 1999**

## TABLE OF CONTENTS

LIST OF TABLES .....	4
LIST OF FIGURES .....	5
ABSTRACT .....	8
INTRODUCTION .....	10
PROJECT OBJECTIVES .....	11
PROJECT RESULTS .....	12
Part I: Objective 1 .....	12
Justification .....	12
Materials and Methods .....	13
Results and Discussion .....	16
Conclusions .....	25
References .....	27
Part II: Objective 2 .....	28
Justification .....	28
Materials and Methods .....	28
Results and Discussion .....	36
Part III: Objective 3 .....	38
Justification .....	38
Materials and Methods .....	40
Organic Mass Degradation and Dry Mass Loss .....	41
Nitrogen Losses .....	43
Specific Oxygen Uptake Rate .....	43
CO <sub>2</sub> Evolution Rate .....	44
Results and Discussion .....	45
Temperature, Moisture Content and % Oxygen .....	45
Changes In Total-N .....	50
Characterization Of Final Product .....	51
Specific Oxygen Uptake Rate .....	56

## TABLE OF CONTENTS (continued)

CO <sub>2</sub> Production Rate .....	56
Conclusions .....	63
References .....	64
 Part IV: Objective 4 .....	 65
Justification .....	65
Materials and Methods .....	66
Results and Discussion .....	68
Conclusions .....	75
References .....	81
 Part V: Objective 5 .....	 82
Justification .....	82
Materials and Methods .....	83
Results and Discussion .....	83
 Attachment A .....	 85
 Attachment B .....	 86
 Attachment C .....	 87
 Attachment D .....	 88
 Attachment E .....	 89
 Attachment F .....	 90

## LIST OF TABLES

Table 1. Volume, mass and carbon to nitrogen ratios of wood chips, Rice hulls, bagasse and bark co-composted with crawfish Processing residuals.....	13
Table 2. Characteristics of bulking agents and crawfish processing Residuals .....	13
Table 3 . Dates when fish residuals and bulking materials were added ...	33
Table 4. Examples of nitrogen and carbon content of selected fishery And agro-industrial processing residuals.....	39
Table 5. Final organic matter degradation, dry mass loss, and percent distribution (dry mass basis) of crawfish residuals, rice hulls or recycled compost in feedstock having initial volatile solids for phases I, II and III.....	50
Table 6. Average N loss from each treatment (phase I) expressed as the cumulative mass loss and percentage loss from initial amount...	55
Table 7. Average N loss from each treatment (phase II) expressed as the cumulative mass loss and percentage loss from initial amount...	55
Table 8. Average N loss from each treatment (phase III) expressed as the cumulative mass loss and percentage loss from initial amount...	55
Table 9. Selected properties of final compost product for all treatments...	55
Table 10. Characteristics of rice hulls and crawfish residuals.....	66
Table 11. Carbon, nitrogen ammonium and nitrate concentrations, and C:N ratios in initial and final compost from three windrows and three water regimes.....	69
Table 12. Initial and final concentrations of principal nutrients (g/kg solids) for the three windrows.....	73



## LIST OF FIGURES

Figure 1. Description of the bench scale reactor used to co-compost crawfish processing residuals with four different bulking agents .....	15
Figure 2. Variation of compost mixtures and ambient air temperature with time (days) during the 50-day study.....	17
Figure 3. Compost mixtures volatile solids losses with time (days) during the 50-day study .....	18
Figure 4. Total nitrogen (g N/kg compost ash weight) concentrations versus time (days) .....	19
Figure 5. Total nitrogen (g N/kg compost dry weight) concentrations versus time (days) .....	21
Figure 6. Variation of compost mixtures C:N ratio with time (days) during the 50-day study .....	22
Figure 7. Variation of compost mixtures pH with time (days) during the 50-day study .....	23
Figure 8. Ammonium (mg $\text{NH}_4\text{-N}$ /kg compost dry weight) concentrations versus time (days) .....	24
Figure 9. Nitrate (mg $\text{NO}_3\text{-N}$ /kg compost dry weight) concentrations versus time (days) .....	26
Figure 10. View across Bayou Barataria from marina test site .....	29
Figure 11. The fish cleaning station at the marina test site .....	29
Figure 12. Example fish species cleaned at the marina test site .....	31
Figure 13. A single panel used to fabricate three-bin compost unit ...	31

## LIST OF FIGURES (continued)

Figure 14. View of completed three-bin compost unit .....	32
Figure 15. Plastic sheeting is laid down first to prevent leachate runoff .....	32
Figure 16. Bark and rice hulls compose the first layer in the compost...	34
Figure 17. View showing a layer of fresh fish residuals in compost bin .....	34
Figure 18. View showing the top layer of bark and compost thermometer .....	35
Figure 19. Temperature profile for the Lafitte, LA fish compost project for the period 12/4/97 through 3/31/98 .....	37
Figure 20. Volatile solids concentration (%) and dry mass (g) versus time (days) for four treatments during phase I .....	46
Figure 21. Volatile solids concentration (%) and dry mass (g) versus time (days) for four treatments during phase II .....	48
Figure 22. Volatile solids concentration (%) and dry mass (g) versus time (days) for four treatments during phase III .....	49
Figure 23. Mean total N concentration and content versus time:phase I	52
Figure 24. Mean total N concentration and content versus time:phase II	53
Figure 25. Mean total N concentration and content versus time:phase III	54
Figure 26. Mean SOUR versus time for four treatments: phase I .....	57
Figure 27. Mean SOUR versus time for four treatments: phase II .....	58
Figure 28. Mean SOUR versus time for four treatments: phase III .....	59

## LIST OF FIGURES (continued)

Figure 29. Mean compost CO <sub>2</sub> production versus time for four treatments: phase I .....	60
Figure 30. Mean compost CO <sub>2</sub> production versus time for four treatments: phase II .....	61
Figure 31. Mean compost CO <sub>2</sub> production versus time for four treatments: phase III .....	62
Figure 32. Research windrow with leachate collector system .....	67
Figure 33. Moisture content of compost during 50-day study .....	70
Figure 34. Mean compost and ambient air temperatures .....	71
Figure 35. Change of volatile solids content of compost during 50-day study .....	72
Figure 36. Leachate/runoff pH from L, W and r windrows during the 50-day study .....	74
Figure 37. Ammonium losses in leachate/runoff from the windrow watered by tap water expressed in g/kg Total-N of the initial compost dry mass .....	77
Figure 38. Nitrate losses in leachate/runoff from the windrow watered by tap water expressed in g/kg Total-N of the initial compost dry mass .....	78
Figure 39. Phosphorus losses in leachate/runoff from the windrow watered by tap water expressed in g/kg Total-N of the initial compost dry mass .....	79
Figure 40. Organic carbon losses in leachate/runoff from the windrow watered by tap water expressed as chemical oxygen demand (COD) in g/kg carbon of the initial compost dry mass .....	80

## ABSTRACT

Disposal of crawfish processing wastes poses a challenging problem to the rapidly expanding crawfish industry. Co-composting of crawfish processing residuals with other agro-industrial products is examined as a waste management alternative to landfill disposal. Wood chips, rice hulls, bagasse, and bark were evaluated for use as bulking agents for co-composting with crawfish residuals. The use of bagasse led to the largest reduction in volatile solids, organic-C, particle size and compost bulk volume. Finished compost using bagasse contained the greatest concentration of total nitrogen. Self-heating patterns and decomposition of crawfish residuals were satisfactory using all four bulking agents. The finished products of all compost mixtures were stable and possessed good structure.

Leachate and runoff management from compost constitutes a challenging problem for compost facility designers and operators. The problem is extended where highly putrescent materials, such as fish processing residuals, are composted. Nutrient losses through leaching and rainfall runoff were evaluated over a 50-day period in a pilot-scale windrow composting study. Crawfish processing residuals and rice hulls were mixed in a 1:1 ratio by weight, and the mixture was windrowed on liners to capture leachate and runoff for analysis. Water for wetting the windrows came from three sources: 1) recycled leachate/runoff captured from the windrows, 2) tap water and 3) naturally occurring rainfall. The study showed that a benefit is derived from adding recycled leachate/runoff water to the compost during the early decomposition stages. Moisture and nutrients are added to the compost that would have otherwise been lost and may have caused ground- and surface-water pollution.

Degradation of mass, microbial activity and nutrient content was determined during composting of different mixtures of rice hulls and crawfish processing residuals. This experiment was also undertaken to assess the efficacy of recycling partially decomposed compost with additional raw crawfish processing residuals. Results showed that mixtures containing the higher percentages of crawfish processing residuals had the highest degree of degradability, greater microbial activity and higher

nutrient content. Recycling of partially decomposed compost resulted in a mixture which degraded at a more rapid rate.

A pilot-scale compost study was performed on-site at a marina located along Bayou Barataria in south Louisiana. The purpose of the study was to demonstrate to marina owners and operators the feasibility of compost fish wastes from the marina's fish cleaning station. Normally, these wastes are thrown into the nearest waterway. Fish wastes were composted with bark and rice hulls in a 117-day study. Fish heads and frames were completely decomposed within 21 days after startup. Results showed that composting can be effectively managed by marina personnel with minimal input of time and funds.

## INTRODUCTION

Waste residuals from fish and shellfish processing and related industries are highly organic and putrescent, easily creating environmental problems if they are improperly managed. Composting seafood residuals is a viable disposal option that converts fresh organic materials into a stable, reusable product by the action of microorganisms.

Composting nitrogenous materials like fish and seafood processing residuals with high moisture content requires use of a bulking agent which will absorb excessive moisture, increase porosity of the mixture, absorb odor, and provide a source of carbon to sustain microbial activity. Determining the best combination of different bulking agents is critical to the quality of the finished product and the success of any composting operation. Monitoring changes in compost composition during composting can improve process performance and optimize design parameters.

Management of leachate/runoff from compost is essential in any successful composting operation. These substances contain organic and inorganic pollutants which could have a detrimental affect on surface and ground waters. Leachate/ runoff management posses a challenging problem for compost operators. This is especially true of fish and seafood residuals.

Co-composting lignocellulotic agricultural by-products with fish and seafood processing residuals can transform these wastes into valuable resources. These residuals are rich in nitrogen and readily available carbon and agricultural by-products are high in carbon. Once most of the nitrogen (N) and the readily degradable carbon (C) are consumed by microbes, the decomposition process slows down. Reuse of the composted end product by recycling back into a new compost process is cost effective since it requires less storage capacity and handling operations. Understanding the biodegradability and nutrient retention cycle during composting may enable the operator to optimize the compost process and consistently produce high quality compost.

This project was initiated to conduct evaluations on seafood and fish processing residuals and bulking agents to determine the best combinations of these materials for an efficient compost process. Also, a major focus was to demonstrate to marina owners/operators the efficacy of composting fish

scraps from cleaning stations. Marinas were identified by CZARA (EPA, 1993) as posing an environmental threat from fish cleaning activities. About 160 marinas have been identified in Louisiana. Only about ten percent have fish cleaning stations. However, these are typically located at the larger marinas which are located in environmentally sensitive areas. Therefore, composting fish scraps at marinas could have a significant impact on the state's water resources.

## REFERENCES

Environmental Protection Agency. 1993. *Guidance Specifying Management Measures For Nonpoint Pollution In Coastal Waters*. EPA Pub. No. 840-B-92-002, Washington, D.C.

## PROJECT OBJECTIVES

Objective 1. Evaluate various formulations of amendment materials plus fish and/or crawfish processing residuals which establish the best C:N ratios for the compost to achieve complete biological stabilization in the shortest time span.

Objective 2. Design and fabricate simple and inexpensive static pile vertical tower reactors and compare to the windrow composting method.

Objective 3. Develop a methodology for determining the point at which the composted material has become biologically stable and describe conditions at this point.

Objective 4. Collect, analyze and characterize leachate from static piles and windrows to define potential pollutants and/or process obstacles.

Objective 5. Develop educational materials, hold workshops and/or result demonstrations to transfer project results to the private sector.

## PROJECT RESULTS

### PART I: OBJECTIVE 1

*(NOTE: The results of this objective were published in manuscript form in the Journal of Compost Science & Utilization. A copy of the published article is included as attachment A).*

#### JUSTIFICATION

The crawfish industry in Louisiana alone accounts for approximately 35,000 metric tons of processing residuals annually. These residuals are normally discarded through local solid waste streams, and they usually end up in landfills. Crawfish processing residuals, like any fish or seafood waste product, are highly putrescent and readily attract flies and vermin. Organic leachates are also probable, representing a potential pollutant of ground and surface waters.

A suitable alternative is to compost crawfish processing residuals. The highly organic nature of crawfish residuals makes them amenable to disposal by composting. Similar materials, such as blue crab processing residuals, have been successfully composted for years. It was necessary to identify suitable materials which can be used as bulking agents and co-composted with crawfish residuals. A good bulking agent must provide the proper carbon to nitrogen (C:N) ratio when mixed with the primary compost ingredient. It must also provide porosity, retain moisture and be readily biodegradable.

Materials evaluated as bulking agents in this study were bagasse, wood chips, bark and rice hulls. These materials were chosen since they are readily available throughout most of Louisiana at low cost. Varying mixtures (recipes) of bulking agents and crawfish residuals were evaluated to ascertain which provided the proper mix ratio to achieve complete composting in the shortest time period.



## MATERIALS AND METHODS

The first step in this phase of the project was to determine pertinent physical characteristics of the bulking agents studied. Table 1 lists the bulk density, organic C, total N, C:N ratio and moisture content of the individual materials.

Crawfish processing wastes were composted with each of the four bulking agents for 50-day trials in commercial compost reactors (Barclay recycling Inc., Ontario, Canada). The reactors were fabricated from black recycled plastic, and each had a volume of 0.3-m<sup>3</sup>. The crawfish residuals were mixed by volume with the bulking agents in the following ratios (crawfish residuals:bulking agent): pine chips, 1:5; rice hulls, 1:5; bagasse, 1:6.5 and bark, 1:6.5. The bark was a blend of pine and cottonwood. Table 2 lists the mixture ratios of each bulking agent and the resulting C:N ratio of the mixture. Each compost mixture was replicated three times.

Table 1. Volume, mass and carbon to nitrogen (C:N) ratios of wood chips, rice hulls, bagasse, and bark co-composted with crawfish processing residuals

Mixture	Volume	Mass	C:N
	----- (ww*) -----	(dw**)	
Wood chips: Crawfish	5.0:1	2.7:1	143.5
Rice hulls: Crawfish	5.0:1	1.1:1	47.3
Bagasse: Crawfish	6.5:1	1.2:1	38.5
Bark: Crawfish	6.5:1	3.2:1	55.8

\* Wet weight basis

\*\* Dry weight basis

Table 2. Characteristics of bulking agents and crawfish processing residuals.

Material	Bulk Density	Organic-C	Total-N	C:N	Moisture Content
	(kg/m <sup>3</sup> ww*)	----- (g/kg dw**) -----			(%ww)
Wood chips	255.8	475.9	2.29	207.8	10.4
Rice hulls	104.4	372.0	4.84	76.9	9.5
Bagasse	81.4	436.3	9.28	47.0	53.4
Bark	218.5	442.8	10.74	41.2	39.2

\* Wet weight basis

\*\* Dry weight basis

Compost temperatures were continuously monitored with copper-constantan thermocouples positioned at three equally-spaced depths (d) in the center of each reactor (Fig. 1). Data was stored on a CR7 datalogger (Campbell Scientific, Logan, UT).

The mean height of compost in each reactor was measured twice weekly to determine volume reduction during decomposition. This was done prior to sample collection. Approximately 150-g samples were collected from each of the twelve reactors twice weekly for analysis. Data reported are the means of three replicates. Samples were initially used for gravimetric determination of moisture content (APHA et al. 1992). Particle size was determined after the samples were dried by screening through a series of sieves vibrating for five minutes. Sieve opening sizes used were 25.4-, 12.7-, 9.5-, 6.4-, 2.36-, 1.65-, 0.83- and 0.59-mm. To facilitate comparisons, the mean particle size was calculated using the percentage weight of material retained by different sieves. After sieving, samples were ground (150 mesh screen), thoroughly mixed and stored in air-tight containers. Approximately 5-g sub-samples were combusted at 550°C to determine volatile solids content. A mixture of 1:2 w/w compost to water was used to determine pH of the samples using a Corning model 250 Ion Analyzer (Corning, NY). Approximately 20-mg sub-samples were used to analyze for organic C and total N using a Heraeus model CHN-O rapid Analyzer. Nitrate ( $\text{NO}_3$ ) and ammonium ( $\text{NH}_4$ ) concentrations were determined in KCL extracts (1:10) using a Wescan model 360 analyzer (Wescan Instruments Inc., Deerfield, IL).

Percent oxygen in the compost was measured with a model OT-21 oxygen probe (Demista Instruments, Wheeling, IL). Oxygen measurements showed that the perforations in the sides of the reactors were sufficient to maintain adequate oxygen (19-21% by volume) in all reactors throughout the study. A 30-cm outer layer of bulking agent was maintained during the first 17 days to serve as a biofilter for odor control. A moderate ammonia odor was evident for the first 10-14 days of composting but diminished thereafter. The outer layer of compost proved to be an effective barrier to odors and flies.

Water was added to the compost as needed to maintain moisture content between 40-60%. The compost was turned manually 17- and 38 days after initial blending the materials in the reactors.

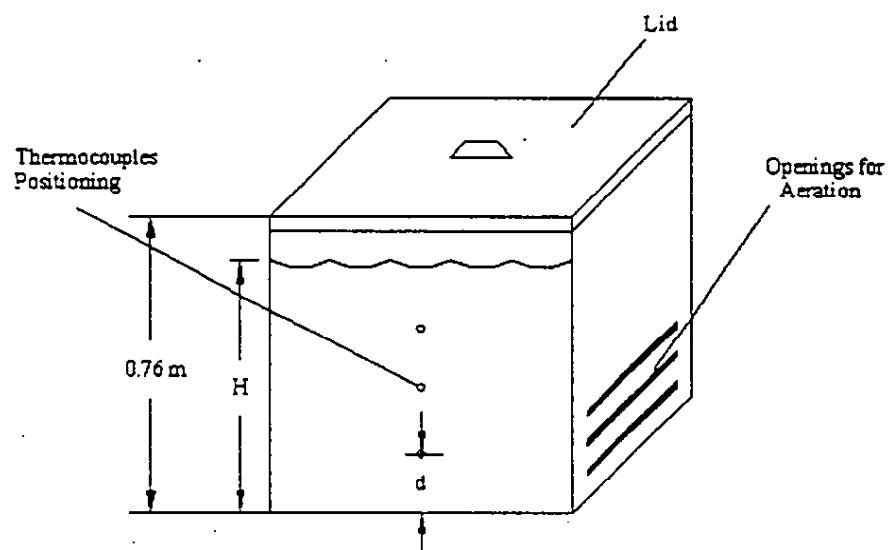


Figure 1. Description of the bench scale reactor used to co-compost crawfish processing residuals with four different bulking agents ( $H$  = height of mixture;  $d = H/4$ ).

## RESULTS AND DISCUSSION

During the first 17 days of composting, moisture content remained in the desirable range (40-60%) during for all mixtures except the rice hull mixtures. Having a high silica content, rice hulls do not retain moisture as well as other bulking agents. However, beyond day 7, the rice hull compost moisture content remained between 40-60%. Apparently rice hulls are better able to retain moisture after they have decomposed slightly. Although moisture content of the rice hull mixtures was not as high as the other mixtures in the initial stages of composting, they achieved the most rapid self-heating and reached the highest initial average temperatures (Fig. 2). Bagasse mixtures reached the highest average temperature during the remainder of the thermophilic period (third week). The corresponding temperature profiles for wood chip and bark mixtures were 5° – 10°C lower than those of rice hull or bagasse. After 23-d, temperatures in all reactors rapidly declined to near ambient temperature. The cause of this sudden drop is unexplained. Thereafter temperatures rose 2-15°C but remained in the upper mesophilic range (25-40°C). When experiments were terminated after day 50, temperatures in all mixtures were about the same.

From the VS (volatile solids) data, it was apparent that the bagasse mixture had lost the most, among other mixtures, of it's original VS content (27.6%) (Fig. 3). By comparing the percentage of VS lost with the initial C:N ratios, it is apparent that mixture of most VS loss corresponds to the lowest initial C:N ratio, and the mixture with the least VS loss corresponds to the highest initial C:N ratio of the mixture. Part of the VS was lost as carbon dioxide as a by-product of microbial activities. Again, the bagasse mixture has observed the largest loss in organic-C (organic carbon) content (10.7 %) on dry mass (d.m.) basis (Fig. 4a). Bark mixture has observed the next loss in organic-C (6.0 %) d.m. basis. Wood chips and rice hulls mixtures had the lowest percentage loss in organic-C content of about 1.1 and 1.3 % d.m., respectively. Since the material d.m. is continuously changing with the composting process due to VS losses, and because the ash mass (a.m.) does not, it becomes necessity, for a better understanding of the process of different mixtures, to base the comparison on ash mass. Significantly enough, the organic-C content shows a continuous decrease throughout the process for all mixtures considering the a.m. basis (Fig. 4b). However, a fluctuation was observed in organic-C content when measurements were based on dry mass due to the changes in VS content.

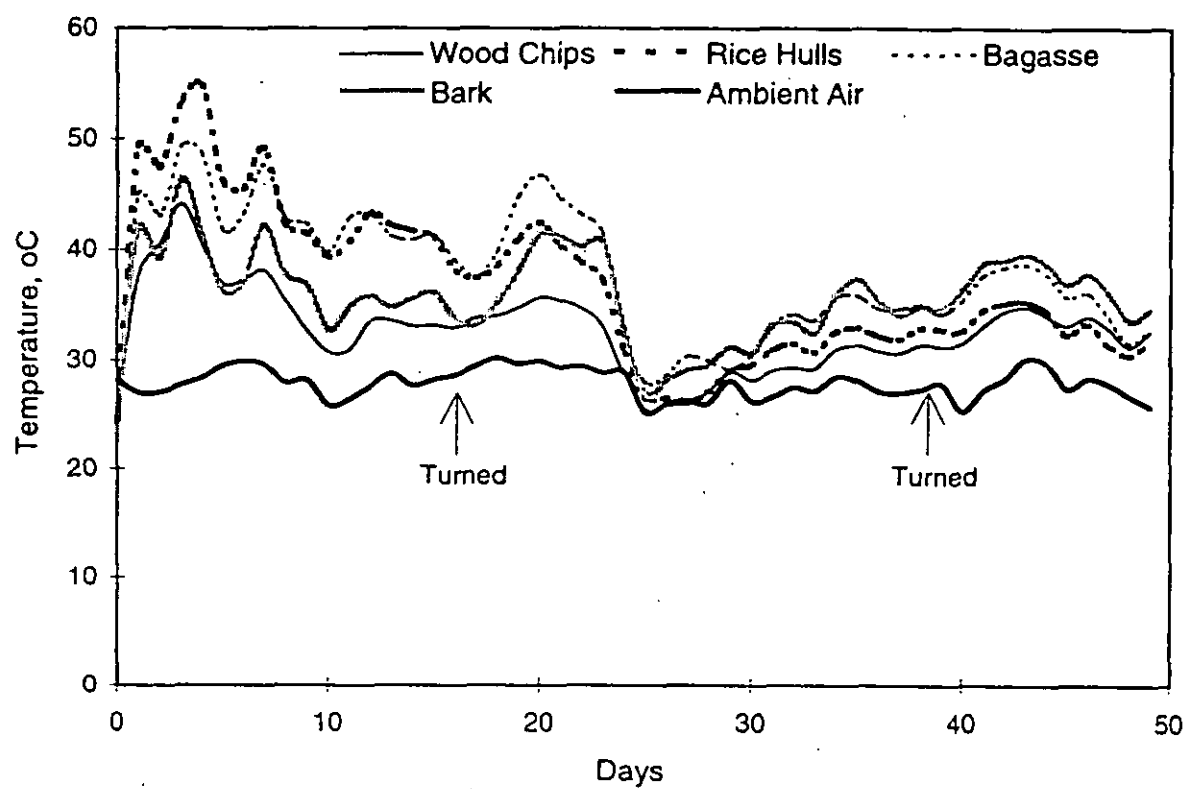


Figure 2. Variation of compost mixtures and ambient air temperatures with time (days) during the 50-day study.

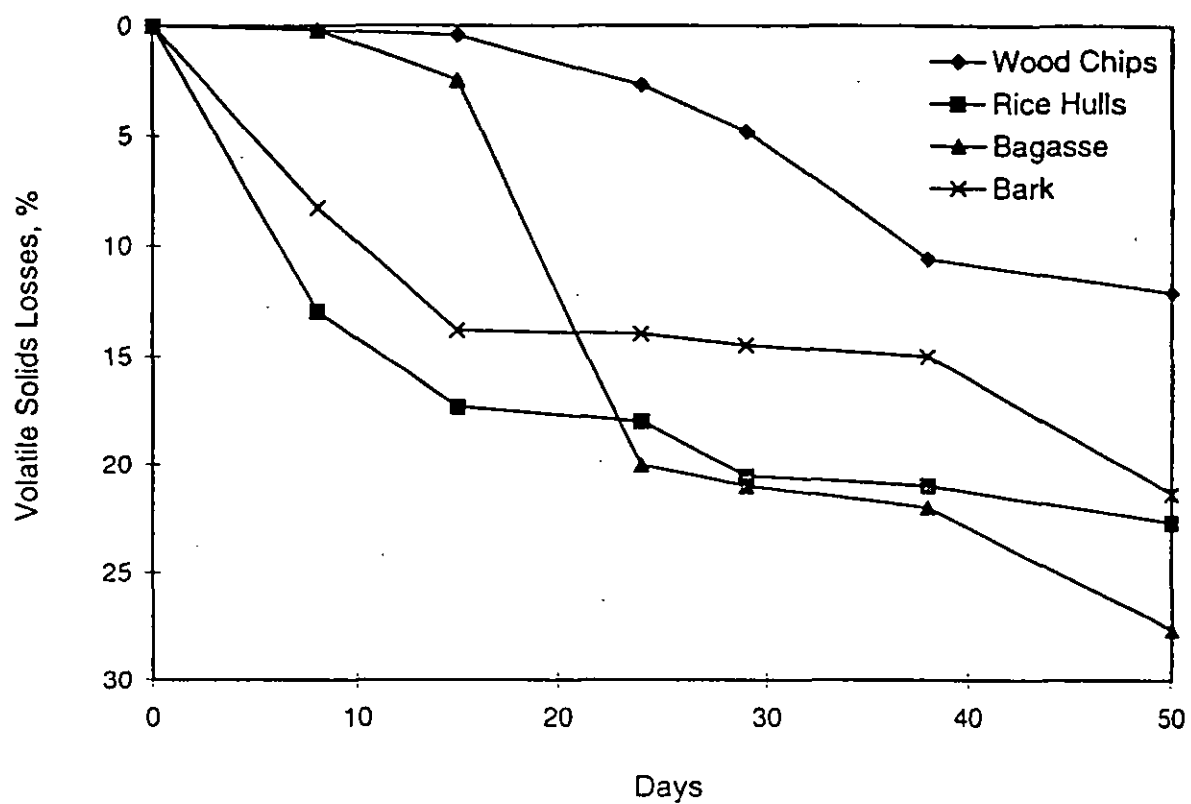


Figure 3. Compost mixtures volatile solids losses with time (days) during the 50-day study.

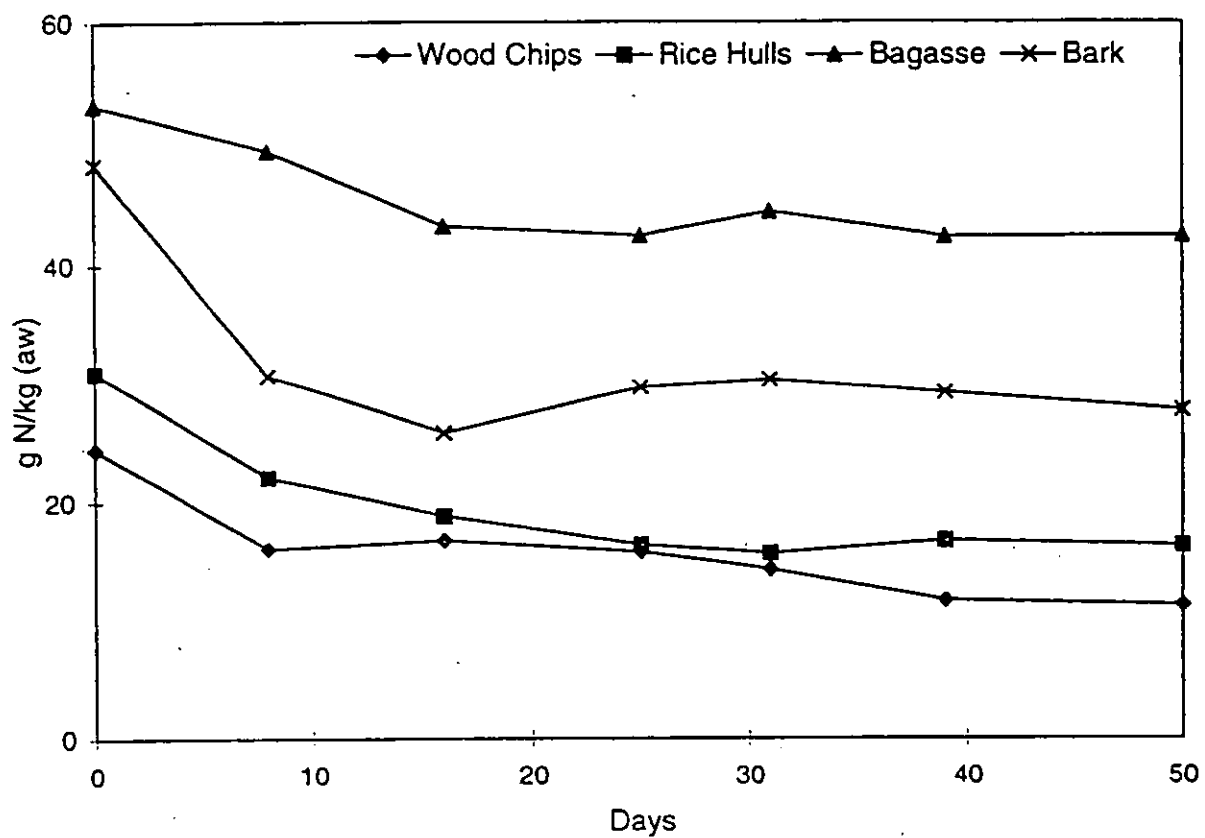


Figure 4. Total nitrogen (g N/kg compost ash weight) concentrations versus time (days).

Percentage organic-C loss on a.m. basis was again the highest for bagasse mixture of about 55.3 %.

Out of the total VS loss, total-N loss was not largely significant in magnitude as organic-C loss because of the different relative amounts needed for microbial activity and the amount present. Normally during composting, material total-N content could decrease substantially (Rynk, 1992). Major total-N loss are contributed to ammonia ( $\text{NH}_3$ ) volatilization as well as subsequent leaching of  $\text{NH}_4$ ,  $\text{NO}_3$  and nitrite ( $\text{NO}_2$ ) in an open system. Throughout the composting process, total-N loss were clearly outlined for crawfish composting with all the bulking agents considered on an a.m. basis (Fig. 5). Maximum total-N percentage loss was from the wood chips reactor of about 53.6% of the original a.m. The rice hulls, bark and bagasse reactors observed 47.2, 42.6 and 20.2% a.m. losses respectively by the end of the fifty day period. Now, if we were to consider the changes of total-N based on d.m., surprisingly, the bagasse mixture had increased significantly by about 59.3% d.m. of its original value. An explanation is that since the bagasse mixture VS or dry mass loss had ousted the N loss significantly, so even the losses of total-N based on the changing dry mass were considered as gain in the term of total dry mass.

Initial compost pH values were about 8.4 for both rice hulls and bagasse mixtures and about 7.9 for both wood chips and bark mixtures (Fig. 6). This initial high pH is contributed to by the ammonification process (Miller, 1992). A similar trend in pH variation was observed for all mixtures. There was a tendency for the pH to decrease during the first 25 days of composting to a value of 7.4 for bagasse and bark and 7.2 for wood chips and rice hulls. This decrease in pH is probably due to a decrease in  $\text{NH}_3$  generation, organic-N mineralization and production of volatile organic acids (Miller, 1992). Later, oxidation of  $\text{NH}_3$  to  $\text{NO}_2$  leads to a pH increase (Haug, 1993). Organic matter decomposition has generated  $\text{NH}_3$  levels in the range of 50 to 400-mg/kg (Fig. 7). After 25 days  $\text{NH}_4$  mineralization to  $\text{NO}_2$  had increased, especially for wood chips and rice hull mixtures (Fig. 8). Bagasse and bark  $\text{NO}_3$  concentrations remained below 25-mg/kg throughout the process. The bagasse mixtures retained the highest  $\text{NH}_4$  concentrations after 25 days.

During composting, organic materials degradation could reduce the overall mixture and bulking agent particle size significantly, which also means a reduction in volume. The bagasse mixture exhibited the greatest



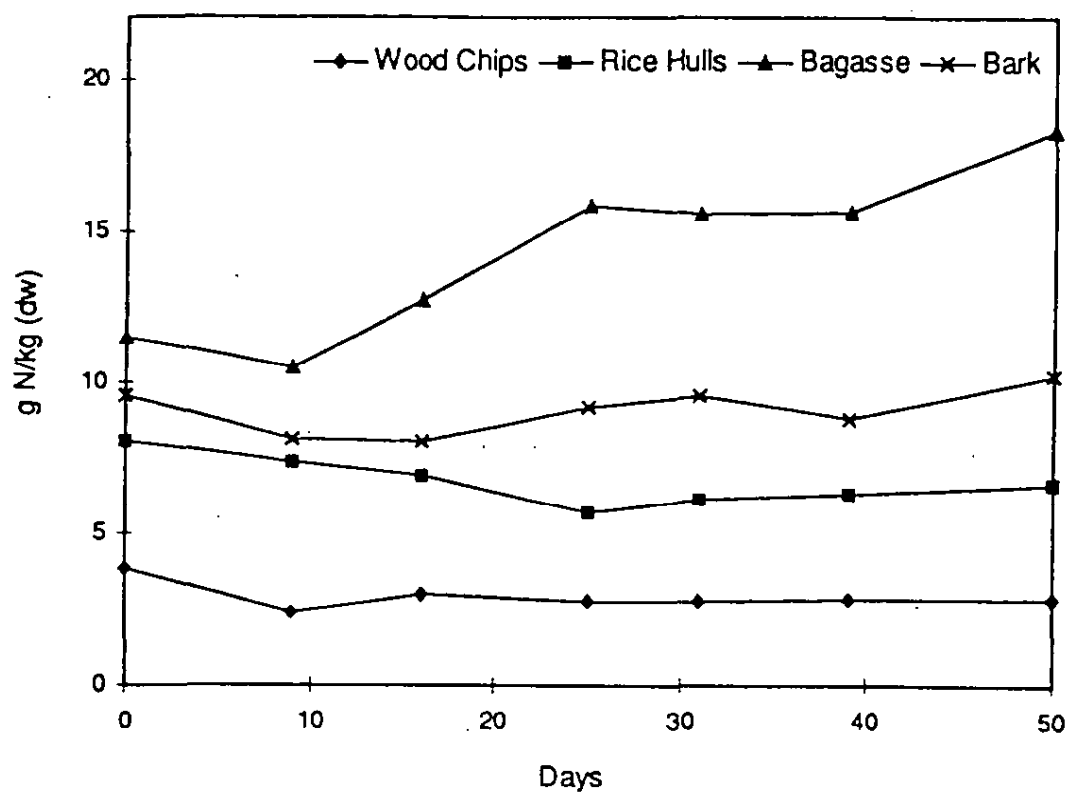


Figure 5. Total nitrogen (g N/kg compost dry weight) concentrations versus time (days).

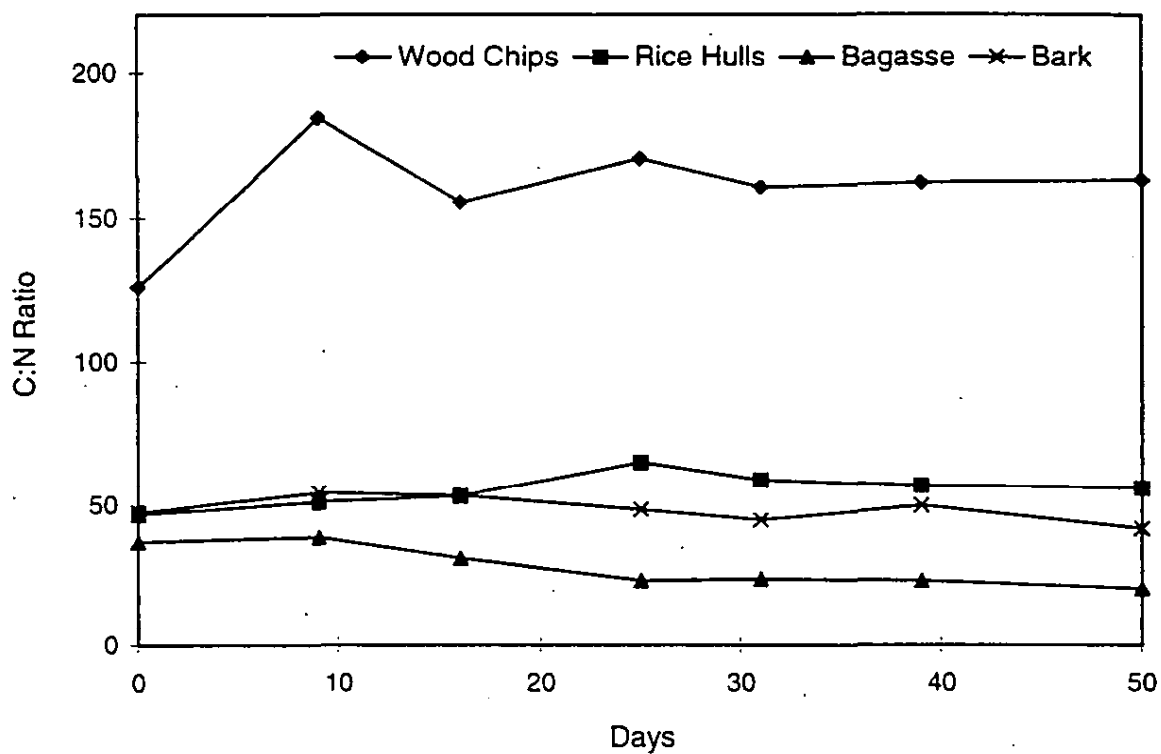


Figure 6. Variation of compost mixtures C:N ratio with time (days) during the 50-day study.

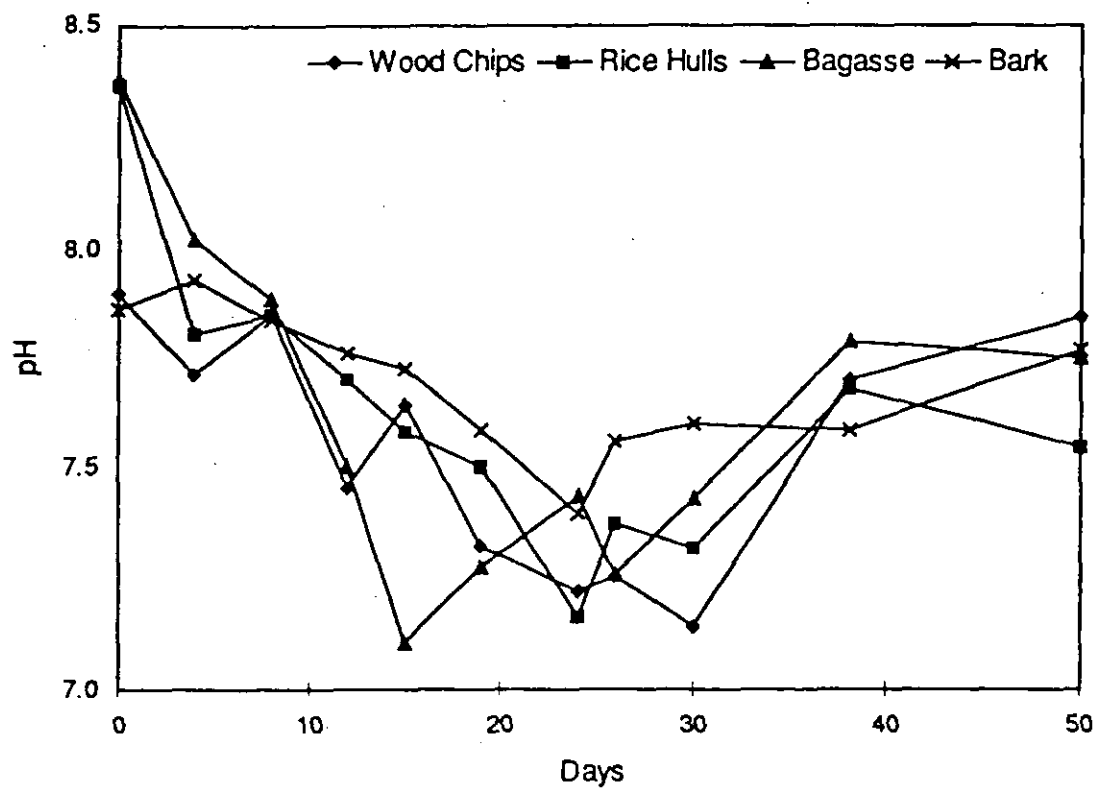


Figure 7. Variation of compost mixtures pH with time (days) during the 50-day study.

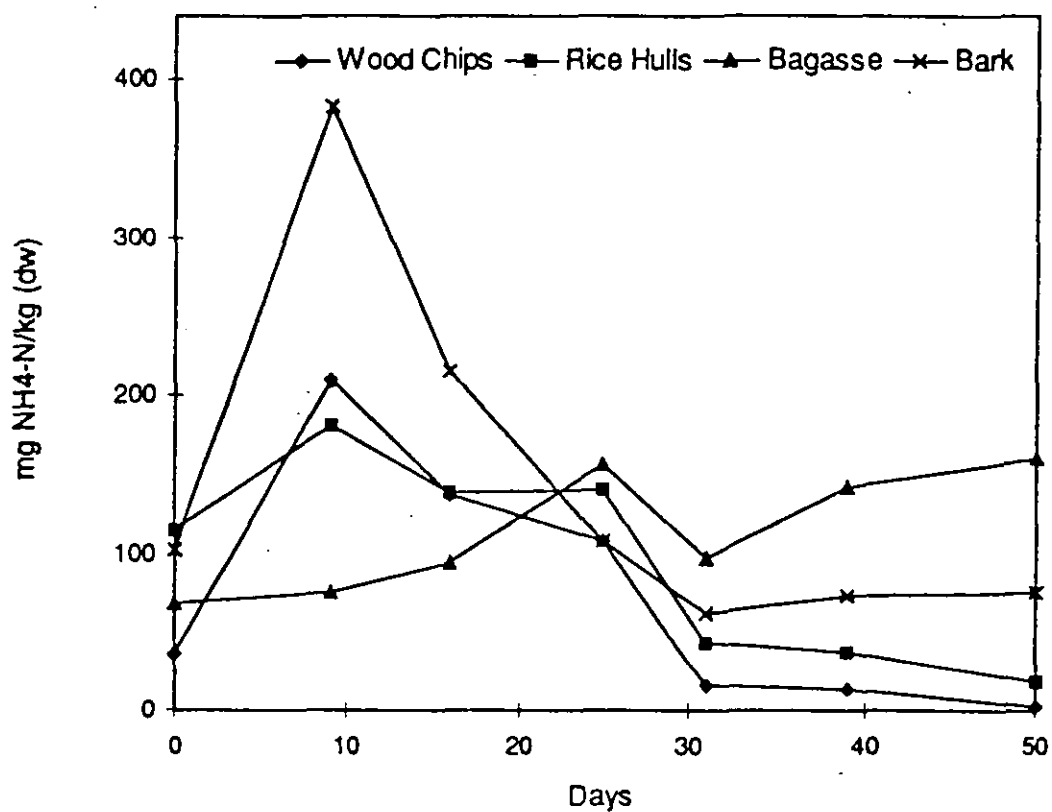


Figure 8. Ammonium (mg NH<sub>4</sub>-N/kg compost dry weight) concentrations versus time (days).

reduction in particle size of about 55% of the original bagasse material and 64.7% of the initial mixture average particle size. For rice hulls, although there was no significant decrease in particle size (1.2%) from the original material, however, the rice hulls were completely degraded (60% reduction of the mixture). Rice hulls have a silica composition which makes them difficult to degrade microbially (Lalche and Nash, 1983). Maximum compost pile volume reduction was observed for the bagasse mixture at 52.8% of its original size over the 50 day period (Fig. 9). The rice hull mixture was reduced only by 16.5%.

### CONCLUSIONS

All bulking materials help degrade the crawfish shells successfully. Compost with bagasse experienced the largest reduction in volume and particle size. Also, the bagasse mixture had the highest nutrient content in terms of total-N and  $\text{NH}_4$ . Wood chips and rice hulls mixtures were least degraded, however, crawfish shells were composted successfully. The material recovered could be used for mulch or additional seafood by-products composting. Reuse of the compost product for additional composting could reduce the cost for bringing new bulking agents. Biodegradability of bulking agents such as wood chips, rice hulls, bagasse and bark, during composting needs to be studied further to optimize the use of these materials.

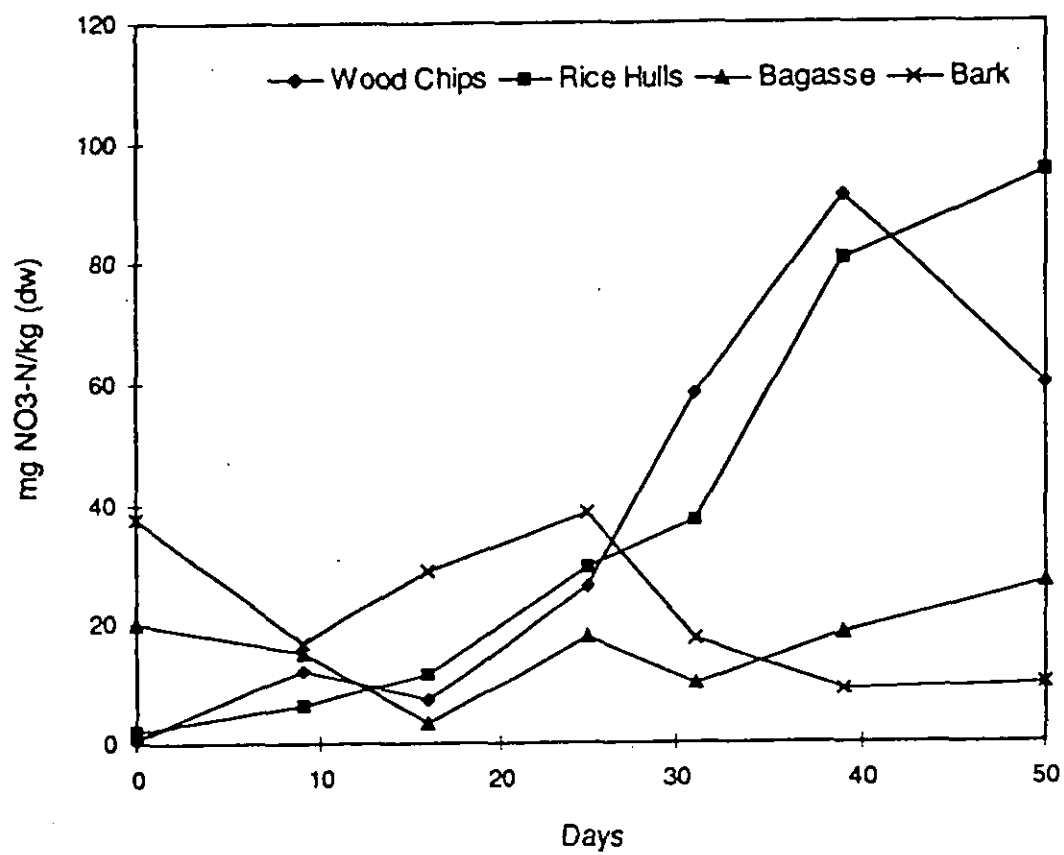


Figure 9. Nitrate (mg NO<sub>3</sub>-N/kg compost dry weight) concentrations versus time (days).

## REFERENCES

- American Public Health Association (APHA), American Water Works Association, and Water Environment Federation. 1992. *Standard methods for the examination of water and wastewater*. 18th edition. APHA, Washington, D.C.
- Haug, R. T. 1993. *The practical Handbook of compost engineering*. Lewis Publishers, Boca Raton, Florida.
- Kleit S., C. F. de Hoop, and S. J. Chong. 1994. *An overview of agriforestry waste production and use in Louisiana*. Six National Bioenergy Conference, Reno/Sparks, Nevada.
- Lalche, A. J. and V. E. Nash. 1983. *A preliminary evaluation of composted rice hulls and arkalite as components of a container plant growing medium*. Mississippi Nurseryman's Association. V.1(4).
- Louisiana Seafood Promotion and Marketing Board, 1995. Fact sheet. New Orleans, Louisiana.
- Miller, F. C. 1992. *Composting as a process based on the control of ecologically selective factors*. In: Soil microbial ecology by F. B. Metting, Jr, editor. Marcel Dekker N.Y. p. 515-544.

## **PART II: OBJECTIVE 2**

### **JUSTIFICATION**

Water pollution remains a serious problem in many of the nation's coastal areas. Large amounts of wastes are generated from fish and shellfish processing plants located in coastal areas. Processing residuals must be disposed of in a manner such that it will not harm the environment while at the same time being cost-effective for the processor.

Often, the catch of sports fishermen and small commercial fishermen is cleaned at dockside within small marinas. The waste from the fish cleaning stations is usually collected in a container and discarded overboard at day's end. In order to discourage marina operators and fish processors from discarding fish cleaning/processing residuals directly to waterways or through other environmentally harmful disposal methods, a method is needed by which fish processing residuals can be discarded using more acceptable disposal methods. In the absence of other economical and viable technologies, composting has emerged as a practical solution to this waste disposal problem. Low-technology composting methods have been evaluated as a means for fish processing disposal at marina sites.

### **MATERIALS AND METHODS**

In November 1997, a marina site located in the Lafitte-Barataria, Louisiana area was selected for cooperation on a demonstration compost project. This area was selected due to its thriving commercial and recreational fisheries and because of its relatively close proximity to the LSU campus in Baton Rouge. Lafitte and Barataria are old commercial and recreational fishing communities located in the Louisiana coastal marshlands about 30 miles south of New Orleans. Lafitte lies on the Eastern Shore of Bayou Barataria while Barataria lies directly opposite on the western shore. Figure 10 shows a photograph of Bayou Barataria directly adjacent to the marina site.

An agreement was reached with a marina owner whereby we would compost the wastes from their fish cleaning station, shown in Figure 11.





Figure 10. View across Bayou Barataria from marina test site.



Figure 11. View of typical cleaning station at marina test site.

Commercial charter boats and recreational fishermen operating out of the marina often clean their catch at the marina site and discard the wastes into trash barrels. It is then discarded in the city trash or thrown overboard. Mixed fish species were used in, the major species being speckled trout, red drum, black drum, croaker and sheephead. Figure 12 shows an example of the fish cleaned at the marina.

A low-cost passive compost reactor was designed and pre-fabricated in the Biological and Agricultural Engineering Department on the LSU campus. The composter was fabricated from 1"x4"x4' cedar fence boards and 1"x4" lumber. Fence panels measuring 56" long (Fig. 13) were fabricated and arranged to form a three-bin composter as shown in Fig. 14. Before the raw materials were added, a 6-mil thick sheet of Visqueen was placed on the ground and tacked up against the sides of each bin in order to trap leachate (Fig. 15). Each bin could hold approximately 73 ft<sup>3</sup> of compost when filled to a depth of 40 in.

A three-bin composter was used for this demonstration. A suggested composting procedure follows: add raw materials to a single bin until it is full, then fill a second bin. While filling the second bin the first bin should be turned (about 7-14 days after filling) to increase aeration. This can be accomplished by shoveling the compost into the third bin by hand or with mechanical equipment, such as a front-end loader. Thus, the compost from both filled bins could be turned a number of times until completion by moving it from one bin to another.

The composter was installed at the marina site on December 4, 1997. Fish residuals and bulking materials were added after carefully weighing on a small portable platform scale. A single bin was initially loaded with 128-lb. fish waste from the cleaning station, 80-lb rice hulls and 340-lb pine/hardwood bark. The raw materials were added in a bark:rice hull:fish ratio of approximately 4:2:1 by volume. The materials were installed in layers; a several inch thick layer of bark was laid first, followed by a layer of rice hulls (Fig. 16). Figure 17 shows a newly added layer of fresh fish residuals. A 6 to 8-in layer of rice hulls and bark was used to cap the compost to reduce odor and fly problems. As additional materials were later added to the bin, the bulking materials at the top of the bin were moved aside and fresh raw fish residuals were added followed by raw bulking materials.



Figure 12. Example of fish species cleaned at marina test site.



Figure 13. A single panel used to fabricate three-bin compost unit.



Figure 14. View of completed three-bin compost unit.



Figure 15. Plastic sheeting is laid down first to prevent leachate runoff.

Marina personnel collected the fish waste from the cleaning station on weekends and stored them in plastic barrels in a walk-in cooler until LSU researchers returned the following week to add the waste to the compost mixture. Follow-up visits were made several times during the following weeks. Cumulative raw materials added to the compost bin during the period December 4, 1997 - March 31, 1998 are listed in Table 3. A total of 792-lb of fish residuals, 895-lb of bark and 267-lb of rice hulls were added to fill the first bin during this period.

Table 3. Dates when fresh fish residuals and bulking materials were added.

Date	Compost day	Fresh fish added (lbs)	Fresh bark added (lbs)	Fresh rice hulls added (lbs)	Total weight of bulking materials (lbs)
11/4/97	0	128	340	80	420
12/12/97	8	65	102	40	142
12/23/97	19	292	272	80	352
1/9/98	36	50	136	40	176
1/16/98	43	191	--	--	--
1/29/98	56	18	--	--	--
2/6/98	80	48	45	27	72
TOTALS		792	895	267	1,192

In most compost systems compost temperature is the major parameter used to indicate microbial activity and compost maturity, thus temperature was measured daily during the course of this project. A Rheotemp compost thermometer was inserted into the center of the compost mass (Fig. 18), and the compost temperature was recorded by marina personnel at approximately the same time each day. Data were entered into a notebook given to them for that purpose. Besides temperature, other entries included date, time of day and the initials of the person making the entry. On the days when on-site visits were made by LSU personnel, samples of the maturing compost were collected in plastic bags, sealed and placed into ice chests for transport to the laboratory at LSU for later analysis.



Figure 16. Bark and rice hulls compose the first layers in the compost.



Figure 17. View of fresh fish residuals layer in compost bin.





Figure 18. View showing top layer of bark and compost thermometer.

## RESULTS AND DISCUSSION

The temperature profile for the compost for the first 117-days of composting for period December 4, 1997 - March 31, 1998 is shown in Fig. 19. The arrows indicate the days when raw materials were added to the reactor. The profile followed a typical pattern for compost according to published research literature. The highest temperature (160°F) was reached on day 22. Ambient high/low temperatures on this day were 65/44 (°F). (Temperature and rainfall data were obtained from the nearest weather station at Marrero, Louisiana). After peaking, the temperature rapidly declined to about 54°F on day 26 (ambient = 51/32 °F) as most of the initial available carbon was consumed by microbes. A second peak at 122°F (ambient = 67/59 °F) was again followed by a rapid decline. On day 36 the compost was turned (mixed) to increase aeration. Typical of partially decomposed compost, the increased aeration caused a secondary peak at 148°F on day 67 followed by a decline to 74°F (ambient = 62/35 °F). Afterwards, the temperature showed a few minor peaks and valleys but generally remained near ambient as the compost process approached completion. The mean high/low ambient temperatures for days 70-117 were 79/33 °F. Observing the temperature profile for the full 117-day period, for all practical purposes, one can consider the compost complete by day 70. However, the procedure was allowed to continue for a total of 125 days and was halted on April 9, 1998. Each day raw materials were added, samples of the maturing compost were taken for analysis.



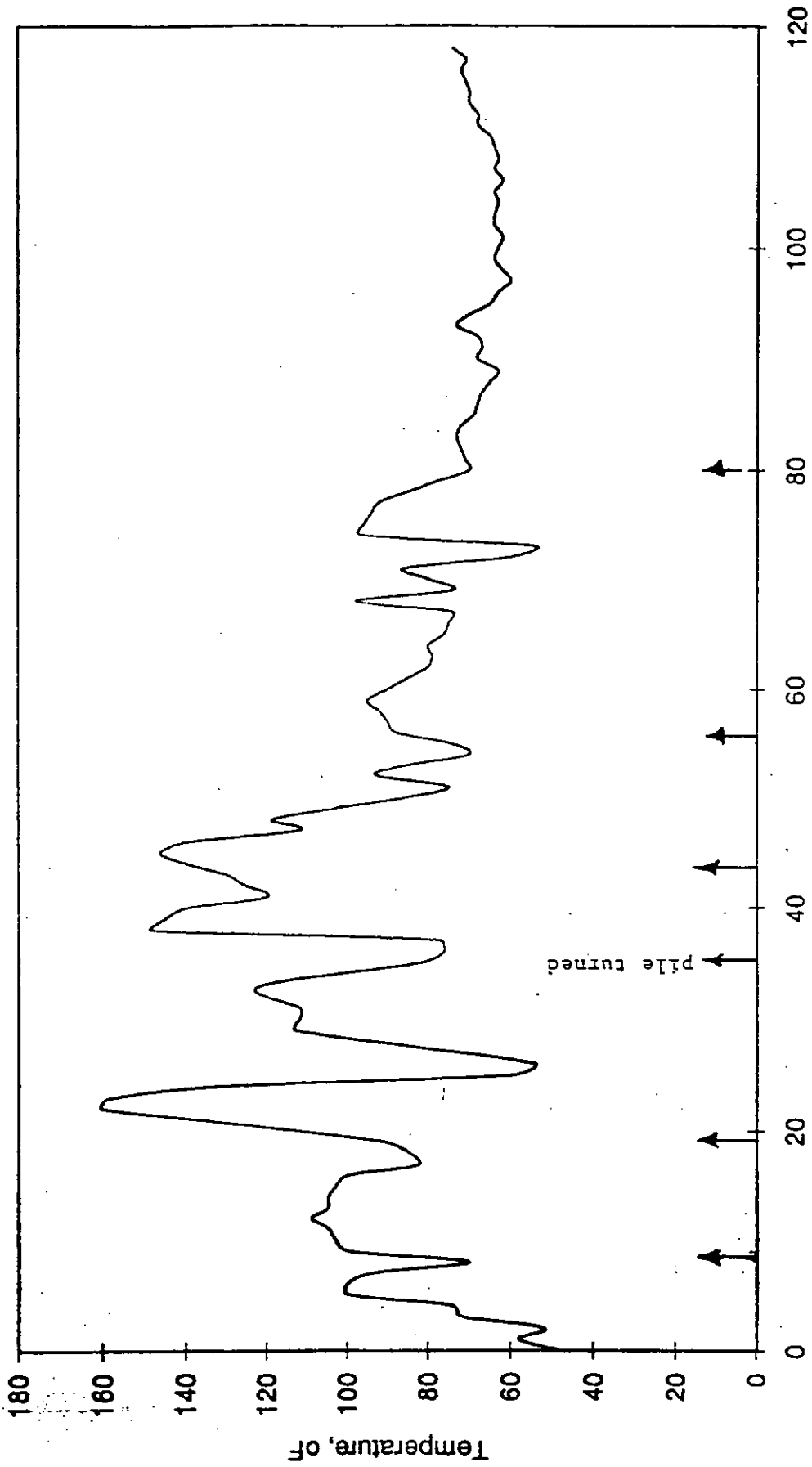


Figure 19. Temperature profile for the Lafitte, LA fish compost project for the period 12/4/97 through 3/31/98. The arrows represent days when fresh fish residuals and bulking materials were added. The pile was turned on 1/9/98.

### PART III: OBJECTIVE 3

*(NOTE: Objectives 1, 3 and 4 were conducted as part of a Ph.D. research project and were published in a dissertation entitled Characterization and Biodegradation of Crawfish and Agricultural Processing By-Product Compost by M.Y. Minkara, Ph.D., 1998, Department of Biological and Agricultural Engineering, Louisiana State University, Baton Rouge).*

#### JUSTIFICATION

Processing by-products from fish and seafood-related industries are highly organic and are typically rich in nitrogen (N) and readily-degradable organic carbon (C) compounds. These materials begin to decompose very soon after processing. Consequently, they become highly putrescent and could potentially create environmental problems if not handled and disposed of properly. By contrast, certain agro-industrial by-products are rich in less-readily-degradable C compounds, particularly lignocellulose (Shuler, 1980). Examples are rice hulls, bagasse, bark, and yard wastes. The high lignin content of these and other materials causes them to degrade slowly under normal conditions (Crawford, 1976).

Fish processing by-products are generally high in N and low in C thus providing a small C:N ratio. These materials may cause odor problems during composting through the production of ammonia and other nitrogenous and organic compounds. Examples of C:N ratios of certain fish and agro-industrial processing by-products are shown in Table 4. By combining N-rich fish by products with materials high in C, such as agro-industrial by-products, the combination C:N ratio can be adjusted to within an acceptable range (20-40) to enhance composting without the associated odor problems. Once the readily available C and available N are consumed during composting, the decomposition rate will slow (Garcia, 1991; Regan and Jeris, 1970). In earlier experiments with crawfish processing residuals and rice hulls, results demonstrated that most, if not all, composting was attributed to the degradation of the crawfish residuals since rice hulls contain more than 60 % lignocellulose and 20% silica on a dry weight basis (Mizuki et al., 1993). They also contain low concentrations of macro-nutrients nitrogen (N), phosphorous (P), and potassium (K). These properties make rice hulls less susceptible to attack by microbes and consequently degrade very slowly.

Table 4. Examples of nitrogen and carbon content of selected fishery and agro-industrial processing residuals.

Material	N (g/kg)	C (g/kg)	C:N
Crawfish	50.3	317	6.3
Fish	48.8	177	3.6
Shrimp <sup>^</sup>	95.1	323	3.4
Crab & lobster <sup>^</sup>	61.2	299	4.9
Wood chips	2.29	476	208
Rice hulls	4.84	372	77
Bagasse	9.28	436	47
Hardwood Bark	10.7	443	41

<sup>^</sup> Rynk, 1992.

Having a high C:N ratio, rice hulls must be combined with materials high in N to increase the rate of degradation. The slow degradation rate of rice hulls allows them to be reused as bulking material by simply adding raw crawfish residuals to the previously composted rice hull-crawfish residual compost. A cost saving in bulk materials is thus realized by reusing the rice hulls.

When designing any compost process, knowledge of compost feedstock degradability is essential (Haug, 1993). In this study, dry mass and organic matter losses during composting were estimated in order to assess the degradability of different rice hull/crawfish residual compost mixtures. Nitrogen losses and final compost characteristics were also analyzed in order to assess the nutrient value (N, P, K) of the completed compost mixture.

Specific O<sub>2</sub> uptake rate (SOUR) and CO<sub>2</sub> production are considered key indicators of microbial activity. As organic carbon is degraded, O<sub>2</sub> is consumed and CO<sub>2</sub> is produced. When the organic substrate becomes limited, O<sub>2</sub> consumption and CO<sub>2</sub> production are reduced. Compost is stable once organic matter resists further degradation. The method of determining the rate of CO<sub>2</sub> production is often used to indicate compost stability or "end point" (Feldman, 1995). Usually, when the CO<sub>2</sub> production rate reaches steady state below 5 mg CO<sub>2</sub>-C/g C/day, the compost process is considered stable (Feldman, 1995). In this study, O<sub>2</sub> consumption and CO<sub>2</sub> production rates were estimated and compared for different rice hull/crawfish residual compost mixtures.

The objectives of this chapter were to characterize and compare the degradation rates, microbial activity, and nutrient values of rice hull/crawfish residual compost mixtures and to examine the efficacy of adding raw crawfish residuals to partially composted rice hulls. More specifically, the objectives were to:

- 1) determine dry mass and organic matter losses
- 2) measure nitrogen loss,
- 3) quantify  $O_2$  consumption and  $CO_2$  production during composting
- 4) estimate nutrient values of the final compost.

## MATERIALS AND METHODS

Crawfish residuals were composted with rice hulls in 3-L beakers containing about 600-g of mixed material. Crawfish residuals were ground (5-mm) before mixing with rice hulls. Three replicates of four different mixing ratios of crawfish residuals and rice hulls, were used to obtain initial C:N ratios of 14:1, 17:1, 25:1 and 42:1. The initial C: N ratio is used as the treatment in a 3x4 factorial experimental design. The 12 reactors were placed in an environmental chamber (Lab-Line Instruments, Melrose Park, IL) having the capacity to control temperature between 25 and 70°C.

Three separate runs were performed. A new batch of crawfish residuals was added to the finished product of the first run identified as phase I. This second compost process was identified as phase II. As the degradation rate of phase II slowed, raw crawfish residuals were again added to begin phase III.

Samples were taken once weekly from each reactor to determine moisture, volatile solids, organic-C, and total-N concentrations. Carbon dioxide production rate was continuously monitored and SOUR was estimated 2-3 times weekly. Water was added when necessary to maintain optimum moisture conditions in all reactors (40-65% wet basis). The compost was turned manually 3-4 times weekly to homogenize the mixture. Compost percent oxygen concentrations were measured four times weekly to confirm aerobic conditions.

Moisture content was determined gravimetrically at 60°C (APHA et al., 1992). After drying, samples were ground to 150-mesh size, thoroughly

mixed and stored in air-tight containers for further analysis. Approximately 3-g sub-samples were combusted at 550°C to determine volatile solids content. About 20 mg sub-samples were used for organic C and total N determination using a Heraeus model CHN-O Rapid Analyzer. Elemental analysis of compost extract was determined for the final product by the Inductively Coupled Plasma (ICP) method (APHA et al., 1992). Percent oxygen in the compost air space was measured using a model OT-21 oxygen probe (Demista Instruments, Wheeling, IL).

A simplified version of the procedure described by Iannotti et al. (1993) was used to measure oxygen consumption. Oxygen consumption rate was measured by placing an active compost sample (~ 3 g) in a sealed 220-ml screw-top jar filled completely with de-ionized water. The solution was aerated for 10 seconds. The jar was then placed in a water bath maintained at about 45°C to measure dissolved oxygen (DO) using a stirring bar oxygen probe (YSI 5905) connected to a DO meter (YSI 5100) (YSI Incorporated, Yellow Springs, OH). Dissolved oxygen readings were recorded once each minute for 10 minutes.

Carbon dioxide production was measured by incubating about 15-g of active compost in sealed screw-jar (300-ml) in the control chamber for about 64 hours at a time throughout each phase of the experiment. A gas chromatograph model MT-150G (Tractor, Austin, TX) was used to measure the CO<sub>2</sub> concentration in the jar headspace.

#### Organic Mass Degradation and Dry Mass Loss

Degradation of organic matter is generally determined by a mass balance of the input and output materials. The mass lost during the process represents the total degradation. Dry mass degradability was determined to compare the degradability of rice hull-crawfish residual compost during the three different phases of the experiment. Measuring total mass during the composting process is not always practical and cost effective due to handling of different feedstock and the large volume produced. However, measurement of volatile solids concentration is feasible and a common practice, since aerobic biological activity decreases the volatile solids content by converting organic C to CO<sub>2</sub>. Volatile solids concentration during composting is then used to estimate organic matter degradation. According to the conservation of ash, organic matter degradation is expressed as (Haug, 1993):

$$K_{OM} = \frac{VS_i - VS_f}{VS_i} 100 = \frac{(\%VS_i - \%VS_f)100}{\%VS_i(100 - VS_f)} 100 \quad (1)$$

where,

$K_{OM}$  = total organic matter degradation, %

$VS_i$  and  $\%VS_i$  = initial volatile solids content (g) and concentration (%)

$VS_f$  and  $\%VS_f$  = final volatile solids content (g) and concentration (%).

Total dry mass degradation ( $K_{dm}$ ) is calculated as a function of  $K_{OM}$  as follows:

$$K_{dm} = \frac{dm_i - dm_f}{dm_i} 100 = \frac{(VS_i + Ash_i) - (VS_f + Ash_f)}{dm_i} 100 \quad (2)$$

where,

$dm_i$  = initial dry mass, g

$dm_f$  = final dry mass, g

$Ash_i$  = initial ash mass, g

$Ash_f$  = final ash mass, g.

Because of conservation of ash,  $Ash_i = Ash_f$ .

Also, since,

$$dm_i = \frac{VS_i}{\%VS_i} 100$$

it follows that,

$$K_{dm} = \frac{(VS_i - VS_f)}{\frac{VS_i}{\%VS_i} 100} 100 = \frac{K_{OM}(\%VS_i)}{100} \quad (3)$$

Organic matter or dry mass degradation can be obtained at any time during the composting period once the volatile solids concentration is known. Also, dry mass can be back calculated at any time during the composting period by the relation:

$$dm(t) = \frac{[100 - K_{dm}(t)]}{100} dm_i \quad (4)$$

where,

$dm(t)$  = dry mass, g, at any time (t)

$K_{dm}(t)$  = dry mass degradation, %, at any time (t).

### Nitrogen Losses

A nitrogen mass balance is used to determine nutrient loss during and after the composting process. For example, knowing the total N concentration after a time t of composting, total N losses are found by:

$$m_N(t) = [C_N(t)][dm_i - dm(t)] \quad (5)$$

where,

$m_N(t)$  = total N losses, mg

$C_N(t)$  = total N concentration (mg N/g dry mass).

### Specific Oxygen Uptake Rate

Specific oxygen consumption or uptake rate (SOUR) was calculated from the change of DO over time per g volatile solids [(mg O<sub>2</sub>/g VS)/hr] by the following:

$$SOUR = \frac{dDO}{dt} \cdot \frac{V}{VS} = \frac{dDO}{dt} = \frac{100V}{m(\%VS)} \quad (6)$$

where,

$\frac{dDO}{dt}$  = slope of the fitted curve of the dissolved oxygen (mg/L) versus time (hour)

$V$  = water volume, L

$VS$  = volatile solids content, g

$m$  = dry mass of compost sample, g

$\%VS$  = percentage of  $VS$  in  $m$ , %.

### CO<sub>2</sub> Evolution Rate

The amount of CO<sub>2</sub> evolved during the incubation period was computed as:

$$r_{CO_2} = \left( \frac{V}{22.4} \frac{M_c (\%C)}{m} (\%CO_2 - \text{blank}) \right) / \Delta t \quad (7)$$

where,

$$r_{CO_2} = \text{CO}_2 \text{ evolution rate, } \left( \frac{\text{mg}(\text{CO}_2 - C)}{\text{gC}} \right) / \text{day}$$

$V$  = volume of jar, L

$\% CO_2$  = CO<sub>2</sub> concentration in jar (%) trapped over time,  $\Delta t$  (day)

blank = blank sample CO<sub>2</sub> concentration, %

$M_c$  = molecular mass of C, g

$m$  = dry mass of compost sample in jar, g

$\%C$  = carbon concentration in  $m$ , %

and where, 22.4 L/mole is the standard molar volume constant.



## RESULTS AND DISCUSSION

### Temperature, Moisture Content, and Percent Oxygen

By adjusting the temperature in the control chamber, temperature scheme in the reactors was simulated to the observed temperature profile of the batch mixture of rice hulls and crawfish residuals during an earlier experiment. Temperature was maintained in the thermophilic range (45-60°C) during the first 10 days and upper mesophilic range (35-45°C) during the following 10 days, and lower mesophilic range (25-35°C) thereafter. Temperatures of different reactors at one time were within 8°C during most of the period for all three phases of the experiment.

Percent oxygen in compost air space describes whether aerobic condition is pronounced. Oxygen concentration below 5% inhibits aerobic microorganisms while promoting anaerobes. It is recommended that the oxygen concentration remains above 5% during decomposition (Rynk, 1992). Oxygen concentrations were maintained well above 5% for most of the reactors except for four reactors during the first day of phase I of the experiment. Manually mixing and exposing to air the materials in the reactors provided aerobic conditions.

Moisture content was maintained in the desirable range (45-60%) for all reactors during the three phases of the composting process. Moisture control is necessary to replenish water loss from drying and to assure optimum moisture content for microbial activities.

During all three phases of the experiment, volatile solids content was reduced with the advancement of the biochemical reaction. Initial mixtures having a higher C:N ratio tended to have higher volatile solids content as well. Initial volatile solids contents of 68.4, 72.6, 76.2, and 80.9%, were obtained from mixtures having initial C:N ratios of 14, 17, 25, and 42, respectively. Raw rice hulls and crawfish residuals have volatile solids content of 81.3 and 62.1 %, respectively. During phase I, volatile solids content decreased to values of 63.0, 69.3, 73.5, and 79.3 % for the CN 14, CN 17, CN 25, and CN 42 treatments, respectively, by the end of the 40-day period (Fig. 20).

Phase II was initiated by recycling the product of phase I with a batch of crawfish residuals. Crawfish residuals were added at different amounts to

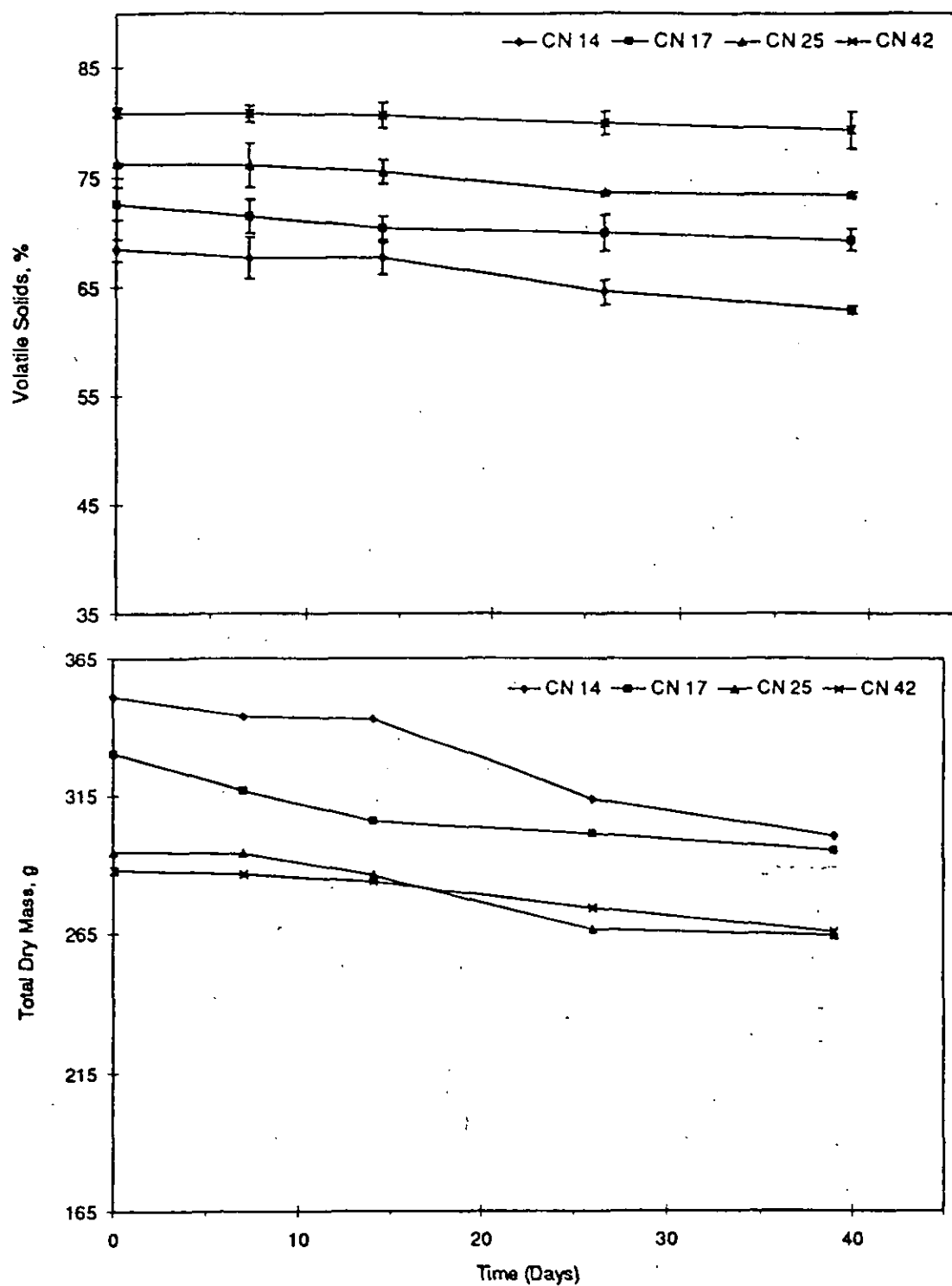


Figure 20. Volatile solids concentration (%) and dry mass (g) versus time (days) for the four treatments during phase I. Data are means of three replicates.

each of the earlier treatments to obtain C:N ratios of : 11, 13, 15, and 20 and initial volatile solids content of 60.3, 64.1, 70.4, and 72.9%, respectively. During phase II, volatile solids in the reactors were continuously decreasing to values of 50.2, 55.5, 65.7 and 67.9%, for CN 11, CN 13, CN 15, and CN 20 treatments, respectively, at the end of the 40-day period (Fig. 21).

Phase III was initiated by recycling the product of phase II with a new batch of crawfish residuals. Initial C:N ratios became as follow: 21, 20, 17, and 18 and initial volatile solids contents were 52.9, 55.2, 59.9, and 62.1%, respectively. In this phase, although all four treatments had relatively similar initial C:N ratios, their initial volatile solids contents were significantly different ( $P=2.6E-06$ ,  $\alpha=0.05$ ). Volatile solids in the reactors continuously decreased, and they reached values of 38.7, 40.0, 49.5, and 51.2 % for CN 21, CN 20, CN 17, and CN 18 treatments, respectively, at the end of the experiment (Fig. 22).

Total dry mass for phase I had a different trend than for phase II and III (Figs. 20, 21 and 22). In phase II and III, total dry mass experienced a sharp decline as commonly observed during the early stages of composting. This decline meant that substrate was readily available for microbial consumption. For phase I, acclimation of microbial population to the newly mixed feedstock delayed this phenomena. Total dry mass reached a steady state toward the end of each phase implying that the exhaustion of the substrate.

The total dry mass loss and organic matter degradation for each treatment during each phase are shown in Table 5. In general, treatments with the lowest percentage of volatile solids had the highest loss of dry mass and organic matter. Although the percentage of crawfish residuals added was about the same at the beginning of phases I, II, and III, for treatment 1 (CN 14, CN 11, and CN 21) and for treatment 2 (CN 17, CN 13, and CN 20), the yield was higher for phase III than phase II or phase I (Table 5). Also, for treatments 3 (CN 25, CN 15, and CN 17) and 4 (CN 42, CN 20, and CN 18), the yield was higher during phase III than phase II, although a similar

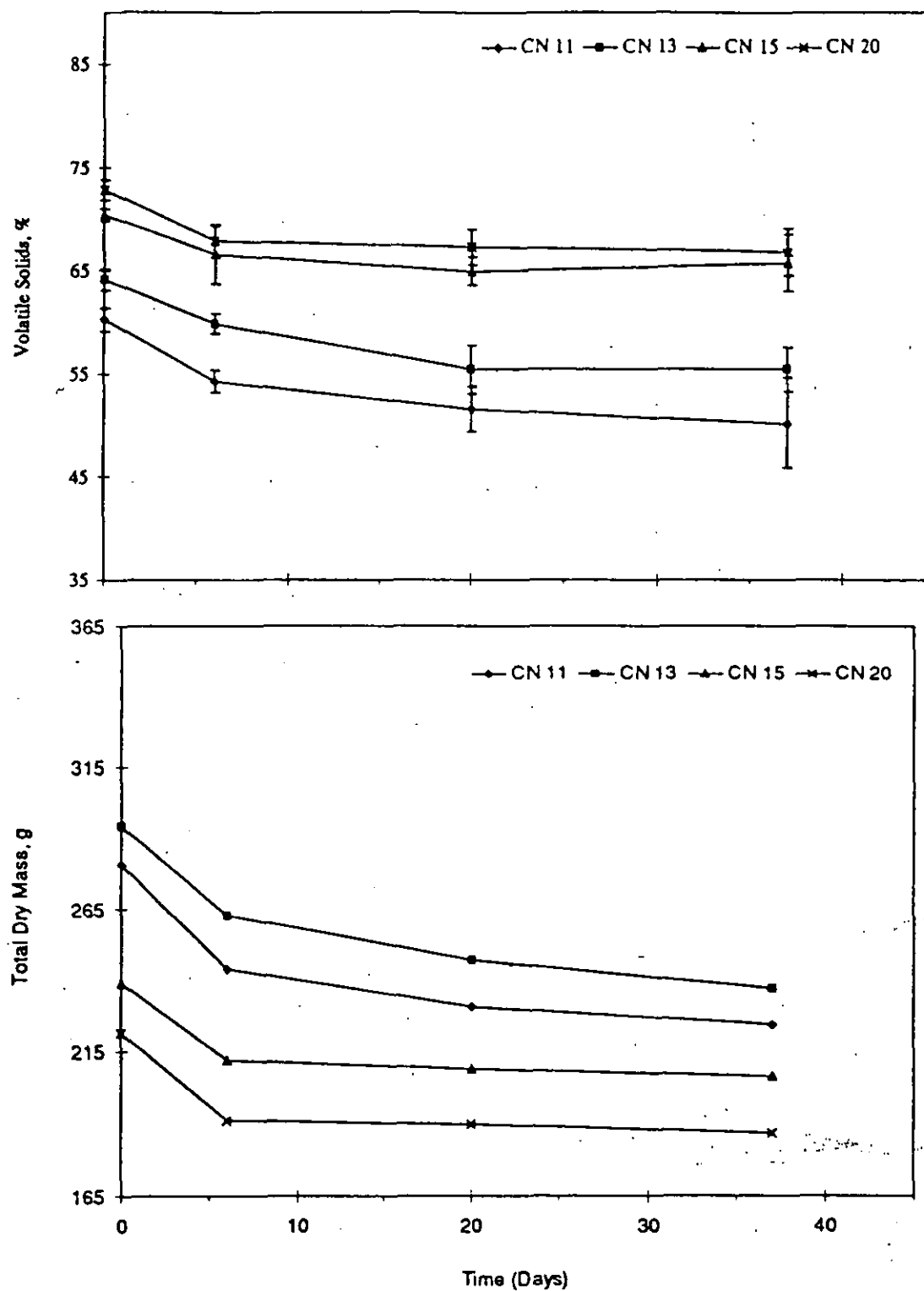


Figure 21. Volatile solids concentration(%) and dry mass (g) versus time (days) for the four treatments during phase II. Data are means of three replicates.

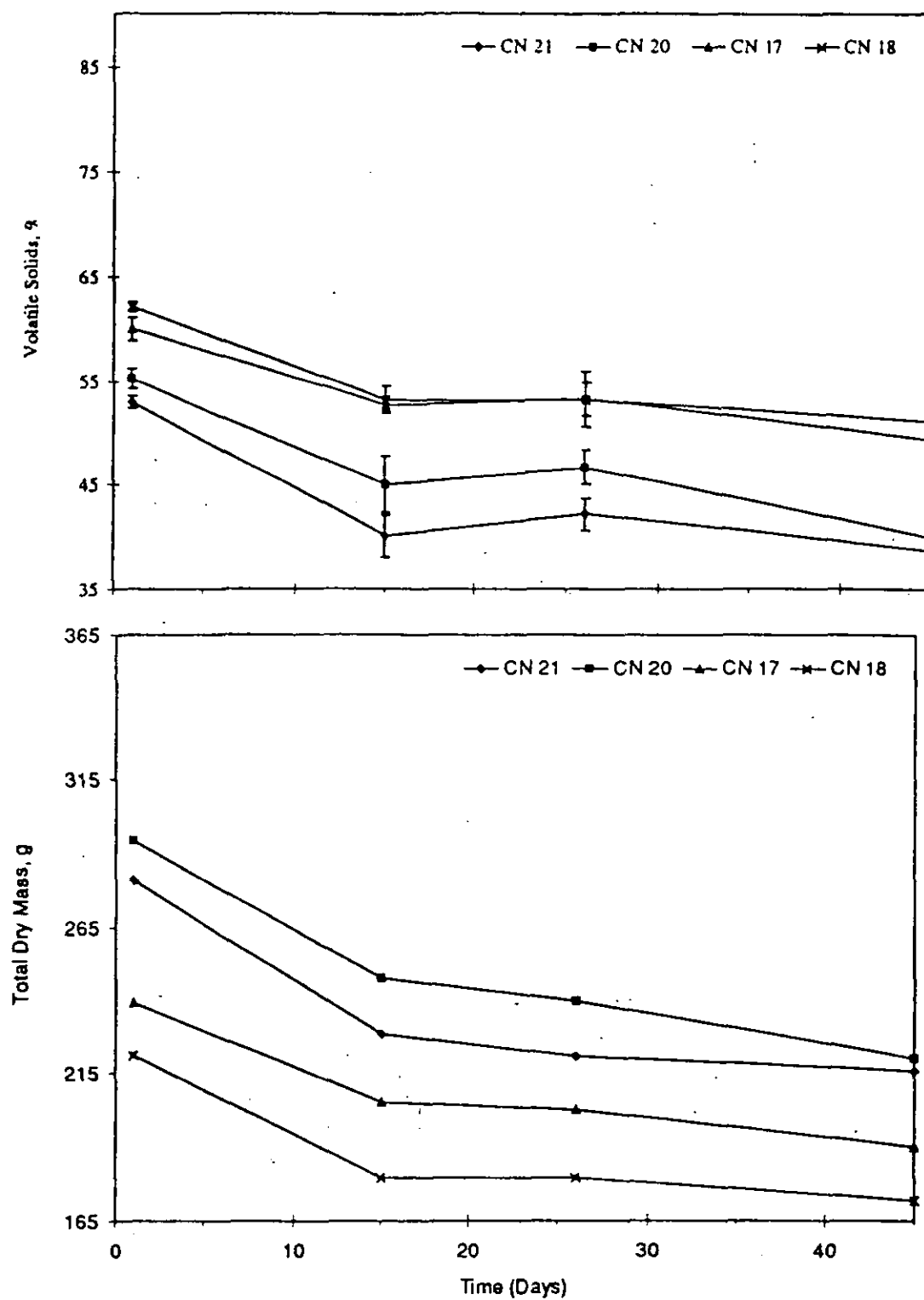


Figure 22. Volatile solids concentration (%) and dry mass (g) versus time (days) for the four treatments during phase III. Data are means of three replicates.

Table 5. Final organic matter degradation ( $K_{OM}$ , %), dry mass loss ( $K_{dm}$ , %), and percent distribution (dry mass basis) of crawfish residuals, rice hulls or recycled compost in feedstock having initial volatile solids,  $VS_i$  (%), for phases I, II, and III. Values are means of triplicate samples.

Phase I					
Treatment	$VS_i$ (%)	Rice Hulls (%)	Crawfish Residuals (%)	$K_{OM}$ (%)	$K_{dm}$ (%)
CN 14	68.4	47	53	21.3	14.6
CN 17	72.6	57	43	14.8	10.8
CN 25	76.2	73	27	13.6	10.3
CN 42	80.9	84	16	9.6	7.8
Phase II					
Treatment	$VS_i$ (%)	Recycled Compost (%)	Crawfish Residuals (%)	$K_{OM}$ (%)	$K_{dm}$ (%)
CN 11	60.3	50	50	33.4	20.2
CN 13	64.1	56	45	30.4	19.5
CN 15	70.4	57	43	19.5	13.7
CN 20	72.9	62	38	21.5	15.7
Phase III					
Treatment	$VS_i$ (%)	Recycled Compost (%)	Crawfish Residuals (%)	$K_{OM}$ (%)	$K_{dm}$ (%)
CN 21	52.9	53	47	43.8	23.2
CN 20	55.2	59	41	46.0	25.4
CN 17	59.9	60	40	34.5	20.7
CN 18	62.1	63	37	35.9	22.3

percentage of crawfish residuals was added. This implies that the degradability is not contributed to the crawfish residuals alone, but also to the recycled materials. So the addition of crawfish residuals has provided an extra means for further degradation of the recycled product. In his model, Haug (1993) has considered that recycle product does not contribute any biodegradable fraction of volatile solids by assuming that the entire biodegradable fraction was consumed during the earlier cycle of composting. The results of this study seem to contradict his findings.

### Changes in Total N

Initial N concentration varied in each reactor according to the ratio of crawfish residuals added to the amount of rice hulls or recycled compost.

The initial N concentrations, for phase I were 28.7-, 23.2-, 16.4-, and 10.1-mg/g (dry mass basis) for CN 14, CN 17, CN 25, and CN 42 treatments. During phase I, nitrogen concentration in all reactors was continuously decreasing over the 40-day incubation period to final values of 10.5-, 10.1-, 8.2-, and 6.7-mg/g, respectively (Fig. 23). When the product of phase I was recycled with more crawfish residuals, N concentration became 28.0, 26.9-, 23.7-, and 19.5-mg/g corresponding to new C:N ratios of 11, 13, 15, and 20, respectively. Also, in phase II, N concentration for all treatments dropped simultaneously to final values of 12.0-, 11.5-, 10.1-, and 8.5-g/kg for CN 11, CN 13, CN 15, and CN 20 treatments, respectively (Fig. 24). The treatments in phase III having initial N concentrations of 13.5-, 14.0-, 15.0-, and 14.2-mg/g corresponded to initial C:N ratios of 21, 20, 17, and 18, respectively. No significant variation in N concentration (dry mass basis) was observed for all treatments in phase III (Fig. 25). This is probably due to the balanced loss of N with that of the total organic matter.

Nitrogen content in each reactor was continuously decreasing throughout the composting period (Figs. 23, 24 and 25 and Tables 6, 7 and 8). Treatments with the highest N content observed the highest drop. This drop occurred during the first 10 days due to high  $\text{NH}_3$  volatilization. After the second week, N content tended to level off between 2- and 4-gN/reactor or a N concentration between 6 and 14 mg/g. N losses during the phase III were minimum. Recycling a recalcitrant compost product such as rice hulls with a nitrogenous source such as crawfish residuals may lead to a conservation of N toward the latest recycling phase.

### Characterization of Final Product

Nutrient analysis of compost samples at the end of the experiment showed that the treatments receiving the highest amount of crawfish residuals have the highest final nutrient concentration (Table 9). The concentration of Si did not vary significantly among treatments. The repetitive addition of crawfish residuals increases the concentration of important nutrients like P, K, Mg, Mn, S, and Ca. These high concentrations provide plant nutrients and improve soil quality. Although high concentration of Na may cause damage to crop, the concentration of Na in crawfish compost remains lower than poultry litter compost (Lu et al., 1997). It was noted earlier that multiple addition of crawfish residuals reduces the VS concentration (i.e. increases ash concentration). Since Ca is a major constituent of ash, the increase of ash concentration lead to an

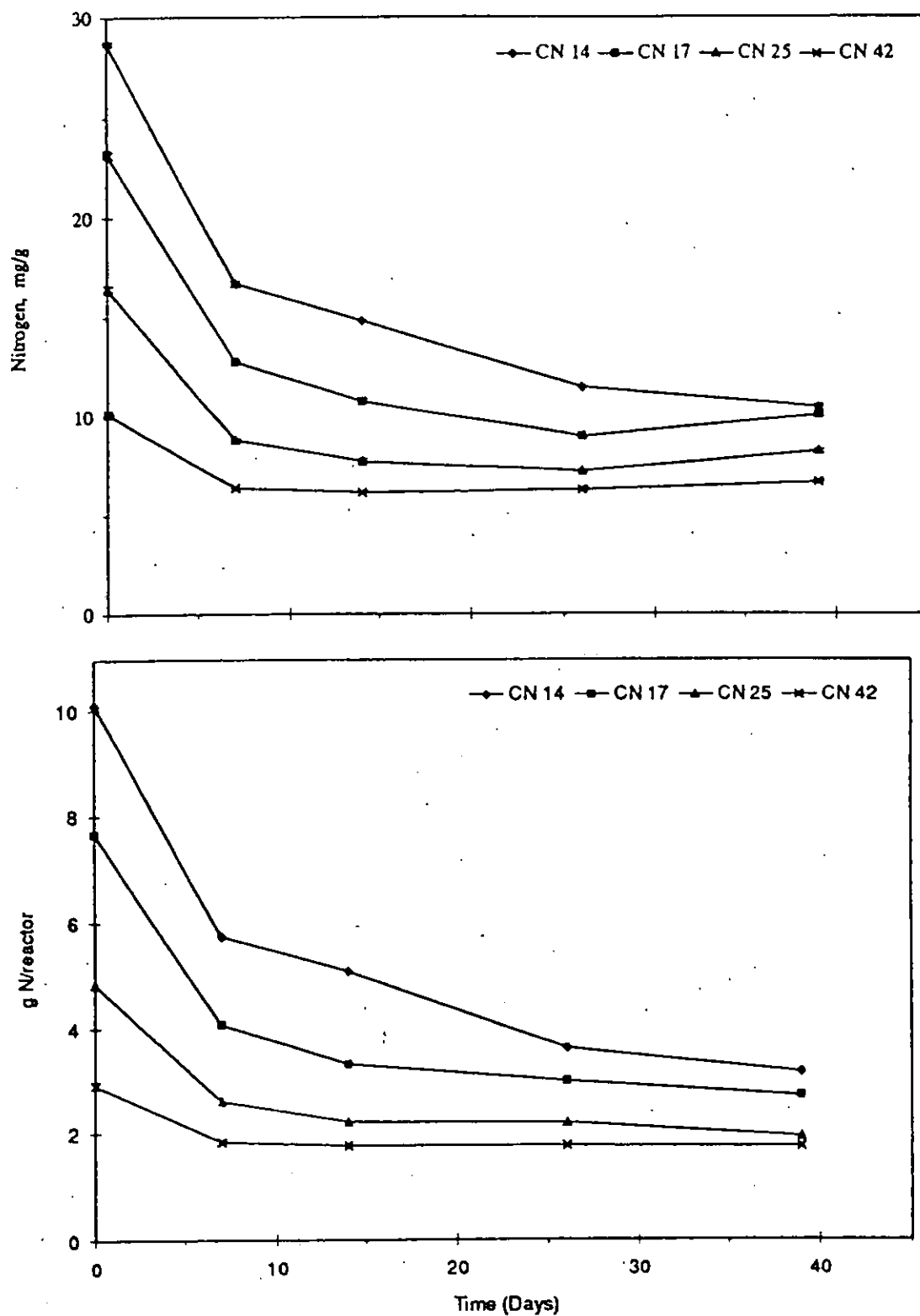


Figure 23. Mean total N concentration (mg/g) and content (g N) per reactor versus time (days) for the four treatments during phase I.



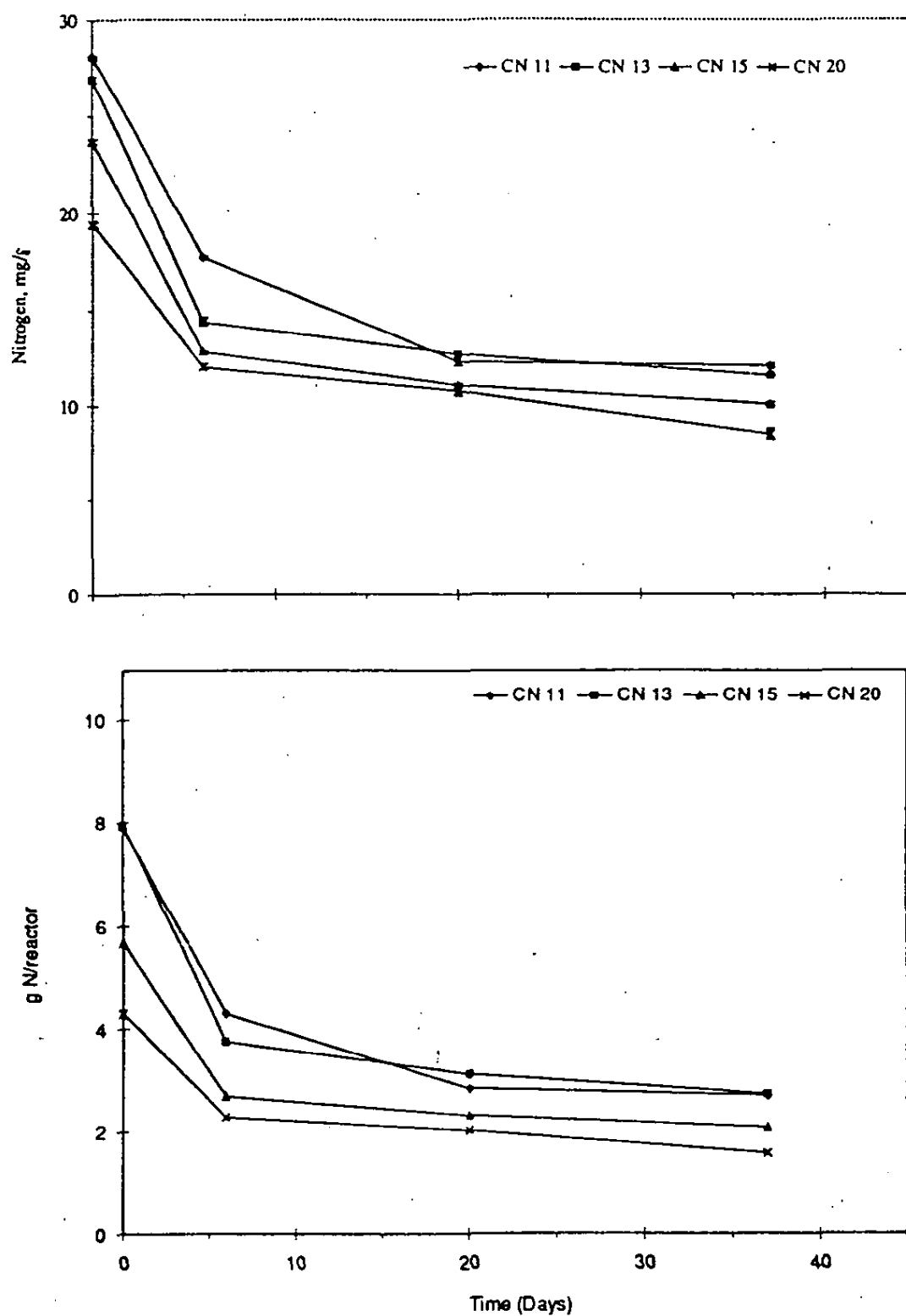


Figure 24. Mean total N concentration (mg/g) and content (gN) per reactor versus time (days) for the four treatments during phase II.

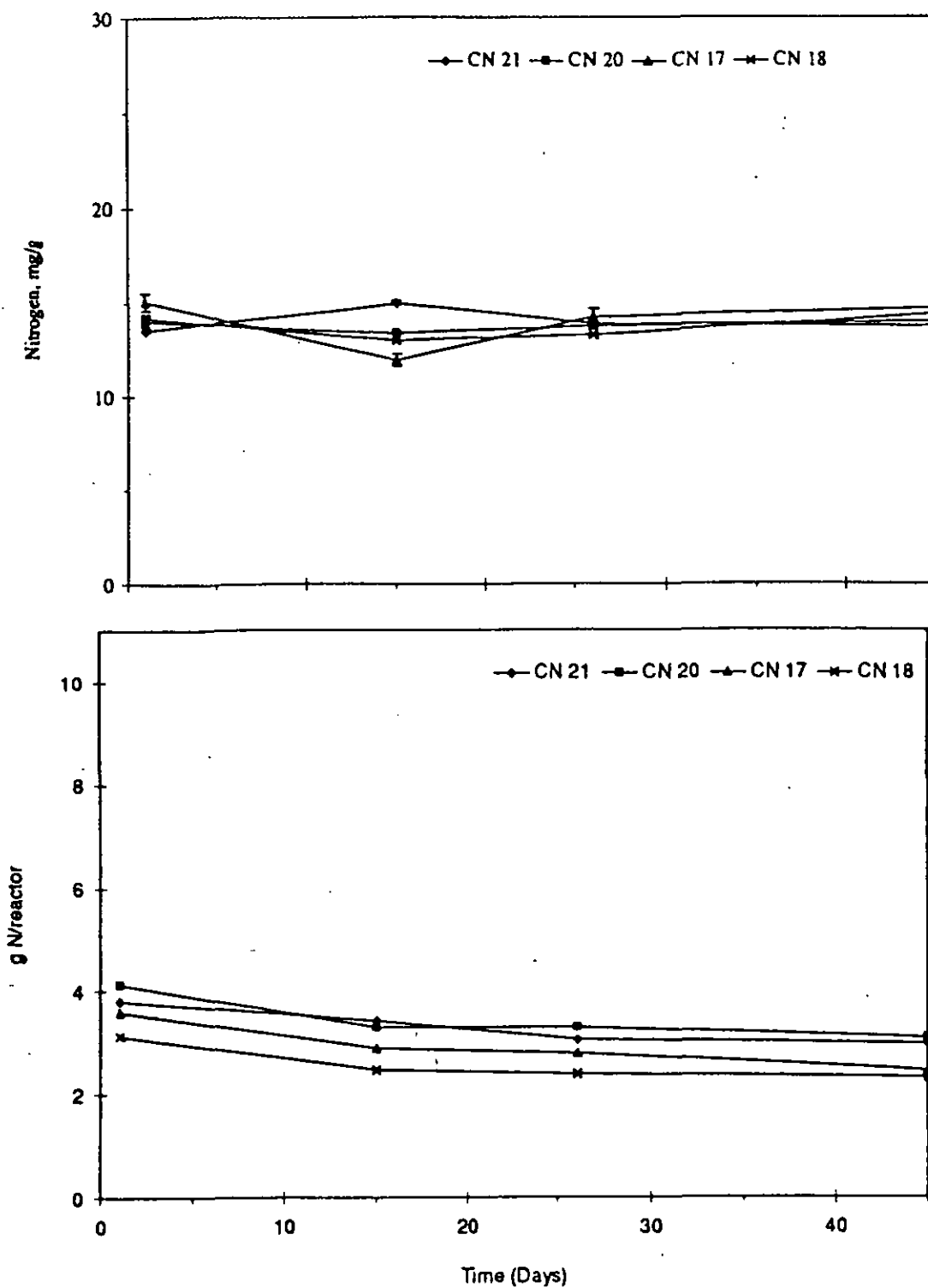


Figure 25. Mean total N concentration (mg/g) and content (g N) per reactor for the four treatments during phase III.

Table 6. Average N loss from each treatment, for phase I, expressed as the cumulative mass loss and percentage loss from initial amount.

Time (Days)	CN 14		CN 17		CN 25		CN 42	
	g N Lost per Reactor	% N Lost of Initial Amount	g N Lost per Reactor	% N Lost of Initial Amount	g N Lost per Reactor	% N Lost of Initial Amount	g N Lost per Reactor	% N Lost of Initial Amount
0	0	0	0	0	0	0	0	0
7	4.35	43.1	3.60	47.0	2.22	46.0	1.56	36.7
14	5.00	49.6	4.35	56.8	2.62	54.2	1.14	39.1
26	6.49	64.3	4.68	61.2	2.66	55.1	1.15	39.5
39	8.96	68.9	4.95	64.7	2.91	60.2	1.18	40.5

Table 7. Average N loss from each treatment, for phase II, expressed as the cumulative mass loss and percentage loss from initial amount.

Time (Days)	CN 11		CN 13		CN 15		CN 20	
	g N Lost per Reactor	% N Lost of Initial Amount	g N Lost per Reactor	% N Lost of Initial Amount	g N Lost per Reactor	% N Lost of Initial Amount	g N Lost per Reactor	% N Lost of Initial Amount
0	0	0	0	0	0	0	0	0
6	3.55	45.1	4.14	52.3	2.96	52.2	2.01	46.7
20	5.03	63.9	4.79	60.5	3.35	59.2	2.27	52.7
37	5.18	65.7	5.19	65.5	3.59	63.4	2.73	63.3

Table 8. Average N loss from each treatment, for phase III, expressed as the cumulative mass loss and percentage loss from initial amount.

Time (Days)	CN 21		CN 20		CN 17		CN 18	
	g N Lost per Reactor	% N Lost of Initial Amount	g N Lost per Reactor	% N Lost of Initial Amount	g N Lost per Reactor	% N Lost of Initial Amount	g N Lost per Reactor	% N Lost of Initial Amount
0	0	0	0	0	0	0	0	0
15	0.38	9.9	0.82	19.8	0.71	19.8	0.68	21.2
26	0.74	19.4	0.82	19.8	0.80	22.3	0.74	23.7
45	0.85	22.4	1.05	25.4	1.14	31.8	0.80	25.7

Table 9. Selected properties of final compost product for all treatments (mg/g).

Treatment	K	P	Na	Mg	Mn	Ca	S	Si
CN 21	6.3	10.2	5.5	2.4	0.34	150.6	3.6	0.068
CN 20	5.9	9.4	5.0	2.3	0.33	138.9	3.4	0.075
CN 17	5.6	8.0	4.5	2.0	0.32	118.4	3.0	0.064
CN 18	5.3	7.5	4.1	1.9	0.30	111.0	2.9	0.065
LSD <sub>0.05</sub> *	0.3	0.4	0.2	0.1	0.01	6.1	0.1	0.02

\* Least significance difference

increase in Ca concentration as well. This is why Ca concentration ranged between 110-150 mg/g.

### Specific Oxygen Uptake Rate

Specific oxygen uptake rate (SOUR) curves were obtained by direct measurements of compost samples at different time intervals throughout the process. A general trend was observed for all treatments in all phases of the experiment (Figs. 26, 27 and 28). Oxygen consumption was at its peak during the first or second day for all treatments of all phases of the experiment. A sharp decline during phase I and phase II and a gradual decline during phase III was then followed, which implies a slowing down in microbial activity. After the second week, SOUR values were below 1.5 (mg O<sub>2</sub>/g VS)/hr for all phases. During phase I, for most part of the experiment, treatment 1 (CN 14) observed the highest oxygen consumption. This implies that more substrate was readily available from the mixture of treatment 1 (CN 14) than to from the others. During phase II and phase III, there was no significant difference in SOUR among treatments except for the first day. Therefore, higher microbial activity was relatively high during the early stage of composting and tends to correspond to the amount of crawfish residuals added.

### CO<sub>2</sub> Production Rate

At the beginning of the compost process, fresh mixture generates ponderous CO<sub>2</sub> emission due to high microbial respiration. As compost ages and available substrate is reduced, CO<sub>2</sub> production decreases. During phase I, initial CO<sub>2</sub> production rates were between 5 and 11 (mg CO<sub>2</sub>-C/g C)/day (Fig. 29). After the first two weeks, CN 25 and CN 42 treatments had a sharp drop. The other two treatments (CN 14 and CN 17) maintained relatively high production rates through the end of phase I. The continuous high CO<sub>2</sub> production for CN 14 corresponded to high substrate availability. Phases II and III CO<sub>2</sub> production rates were very similar among different treatments (Figs. 30 and 31). Unlike phase II and III, a variation in CO<sub>2</sub> production among treatments was observed in phase I. This phenomenon is probably due to the acclimation of the microbial community resulting from the mixing of raw heterogeneous organic materials (rice hulls and crawfish residuals). For phase II and III, a high variation of CO<sub>2</sub> production was observed among samples of the same treatment during the early period than

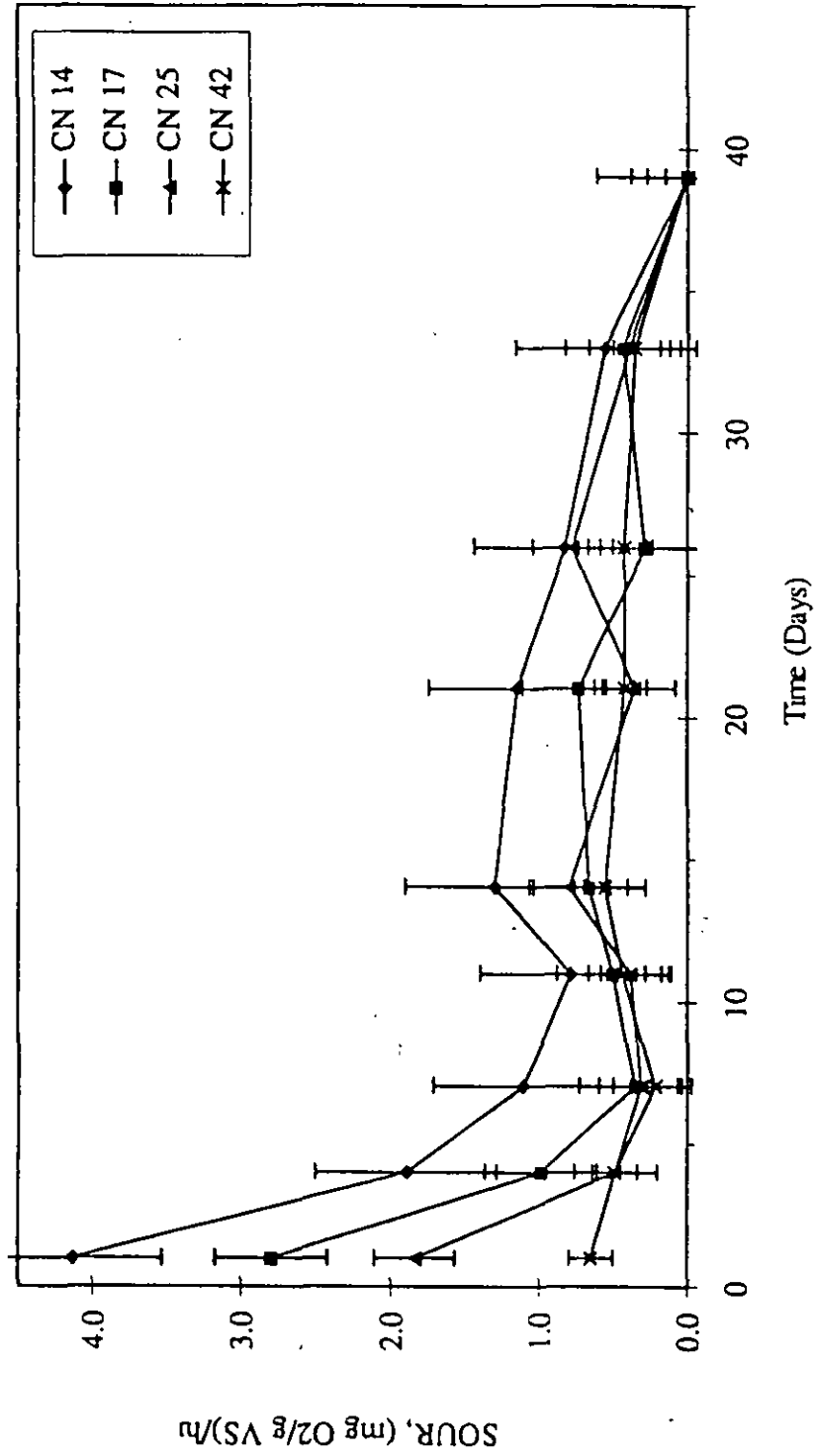


Figure 26. Mean component specific oxygen uptake rate (SOUR) versus time (days) for the four treatments during phase I.

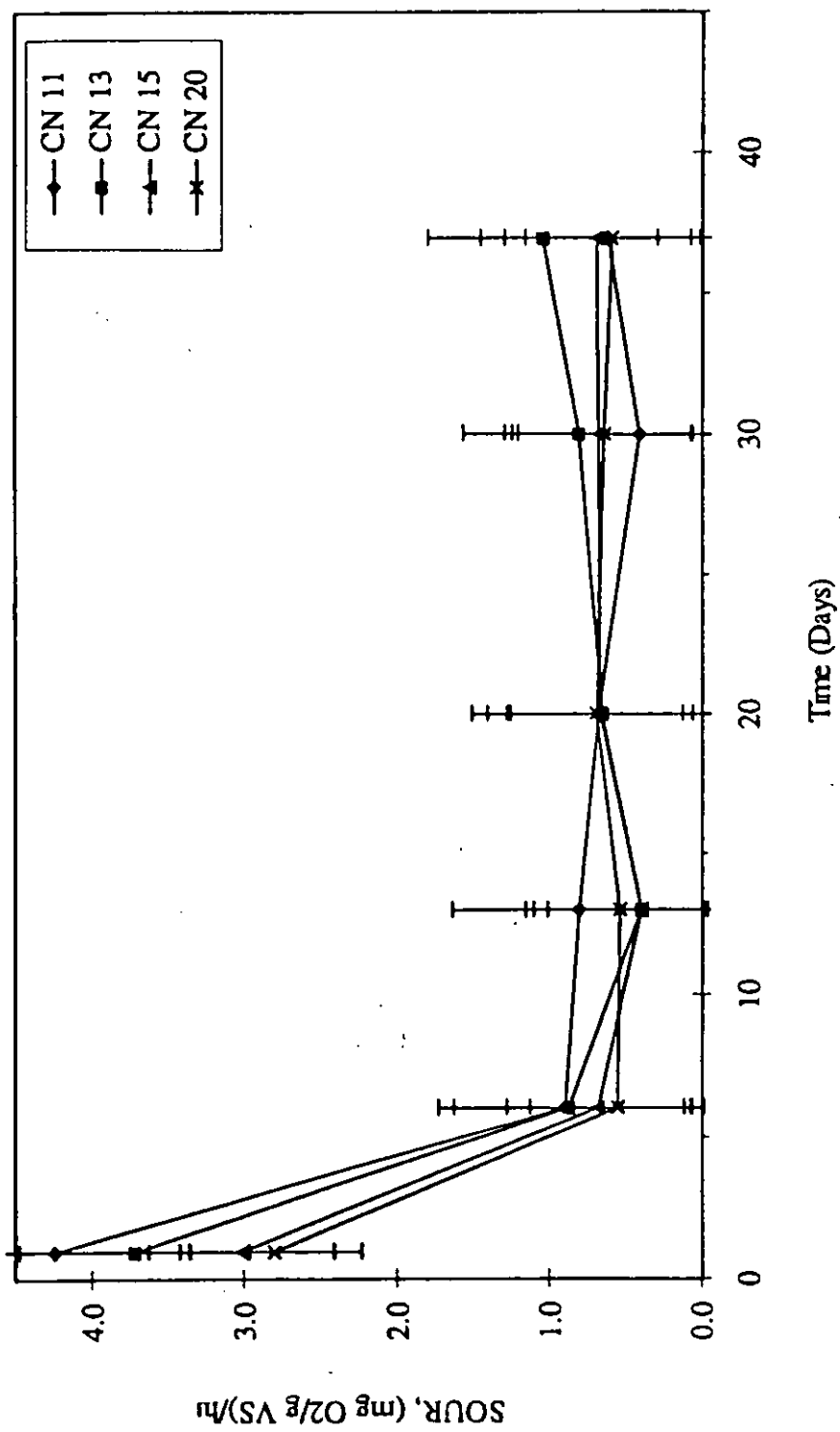


Figure 27. Mean compost specific oxygen uptake rate (SOUR) versus time (days) for the four treatments during phase II.

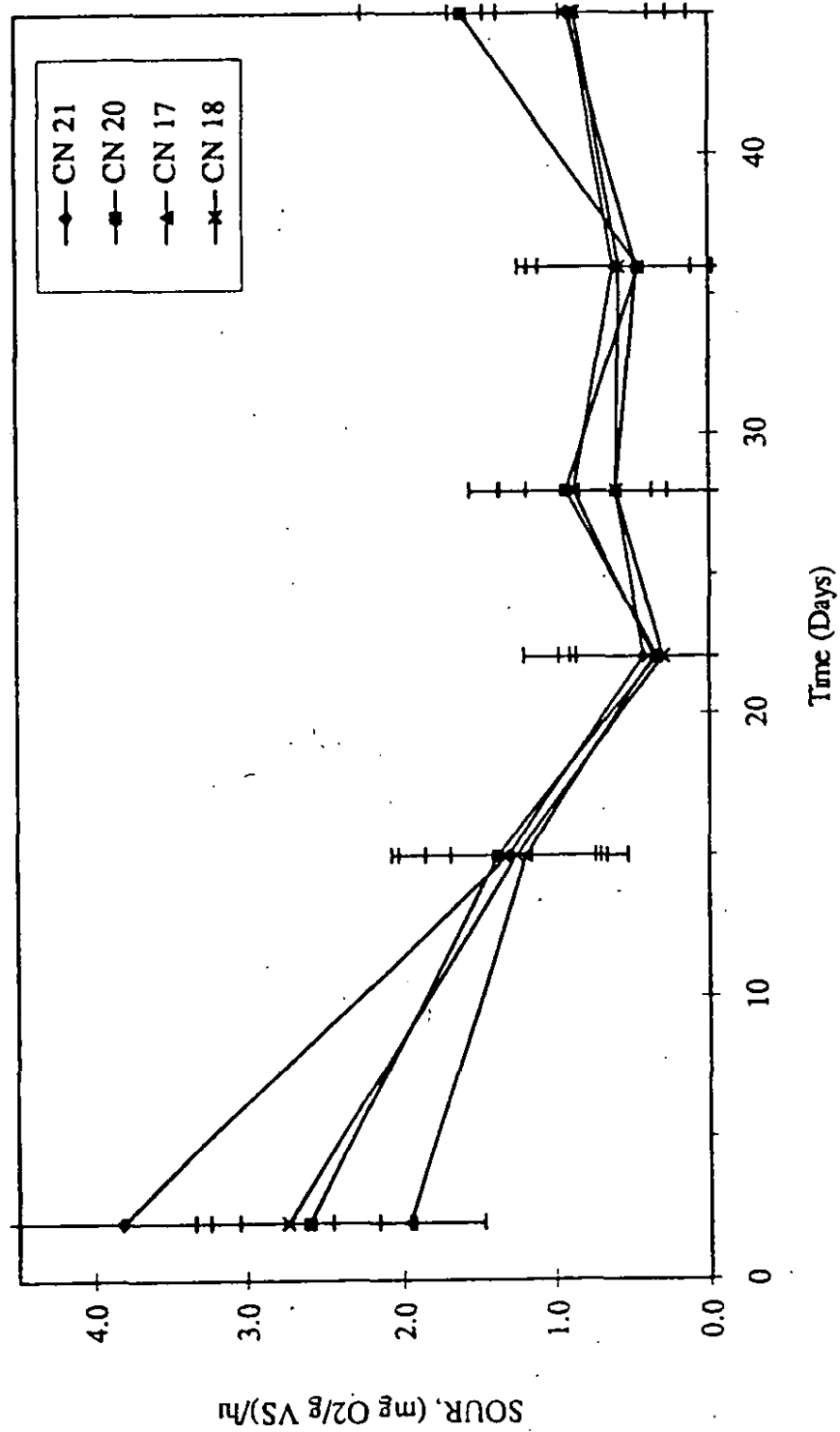


Figure 28. Mean compost specific oxygen uptake rate (SOUR) versus time (days) for the four treatments during phase III.

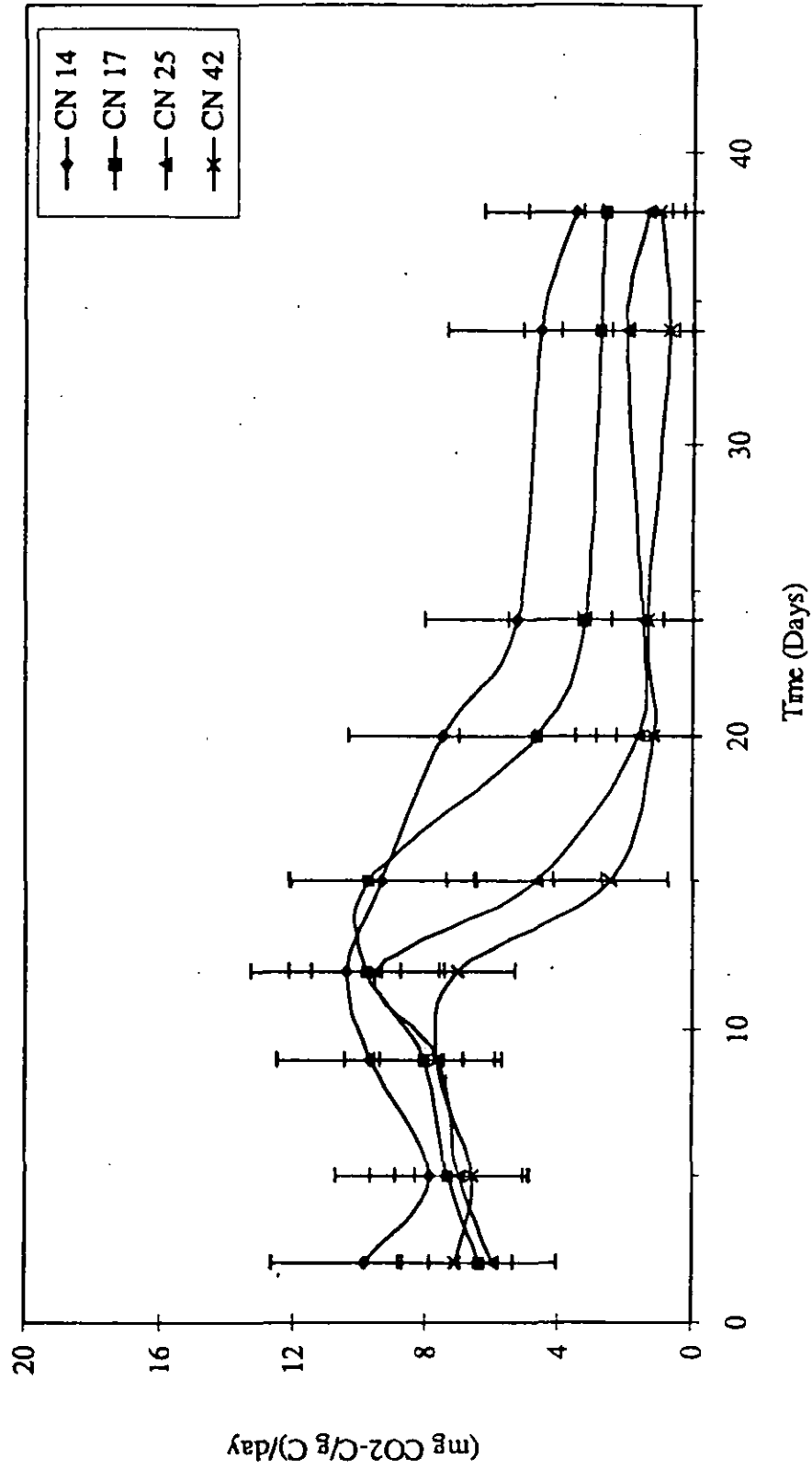


Figure 29. Mean compost CO<sub>2</sub> production rate versus time (days) for the four treatments during phase I.



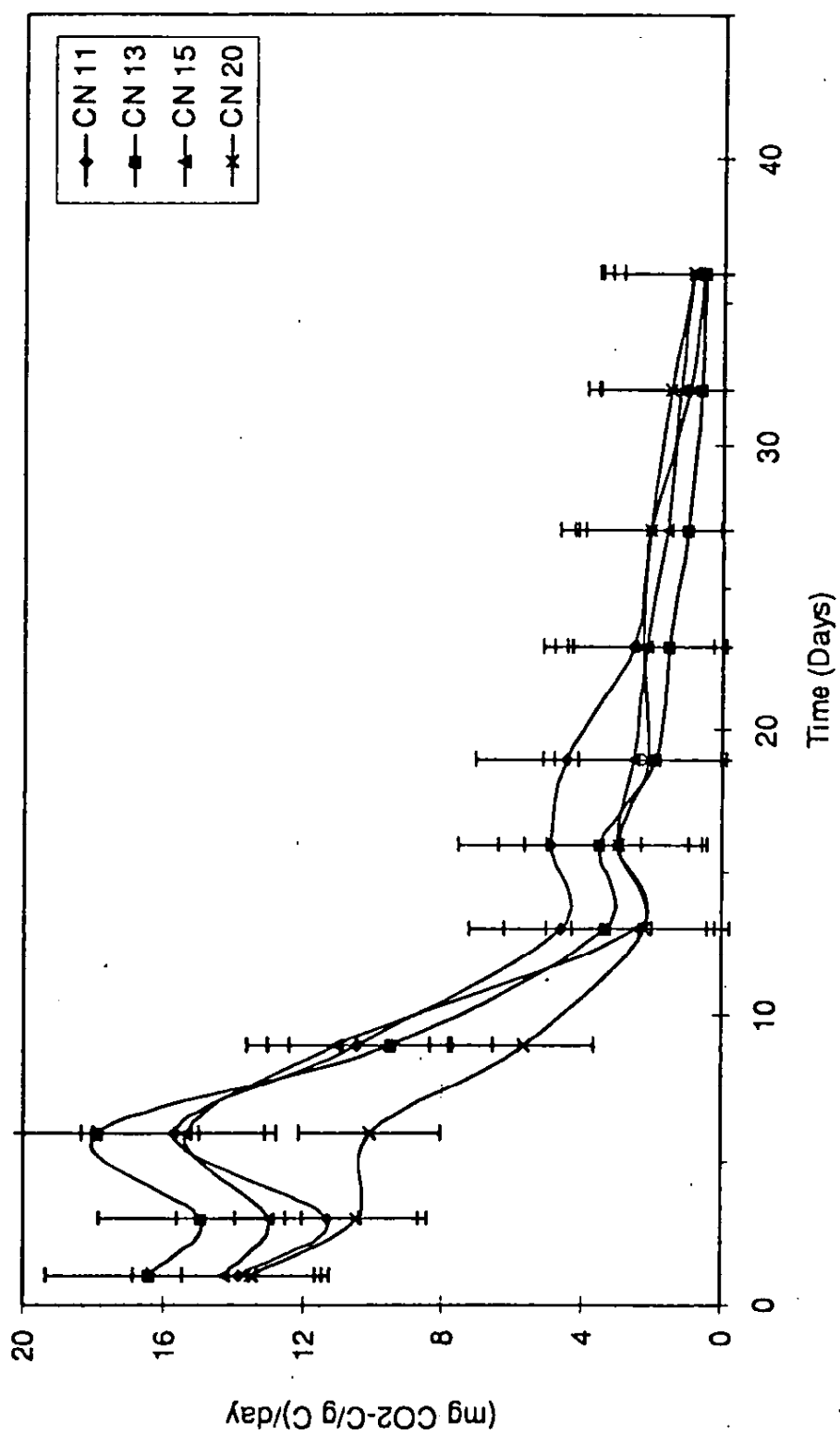


Figure 30. Mean compost CO<sub>2</sub> production rate versus time (days) for the four treatments during phase II.

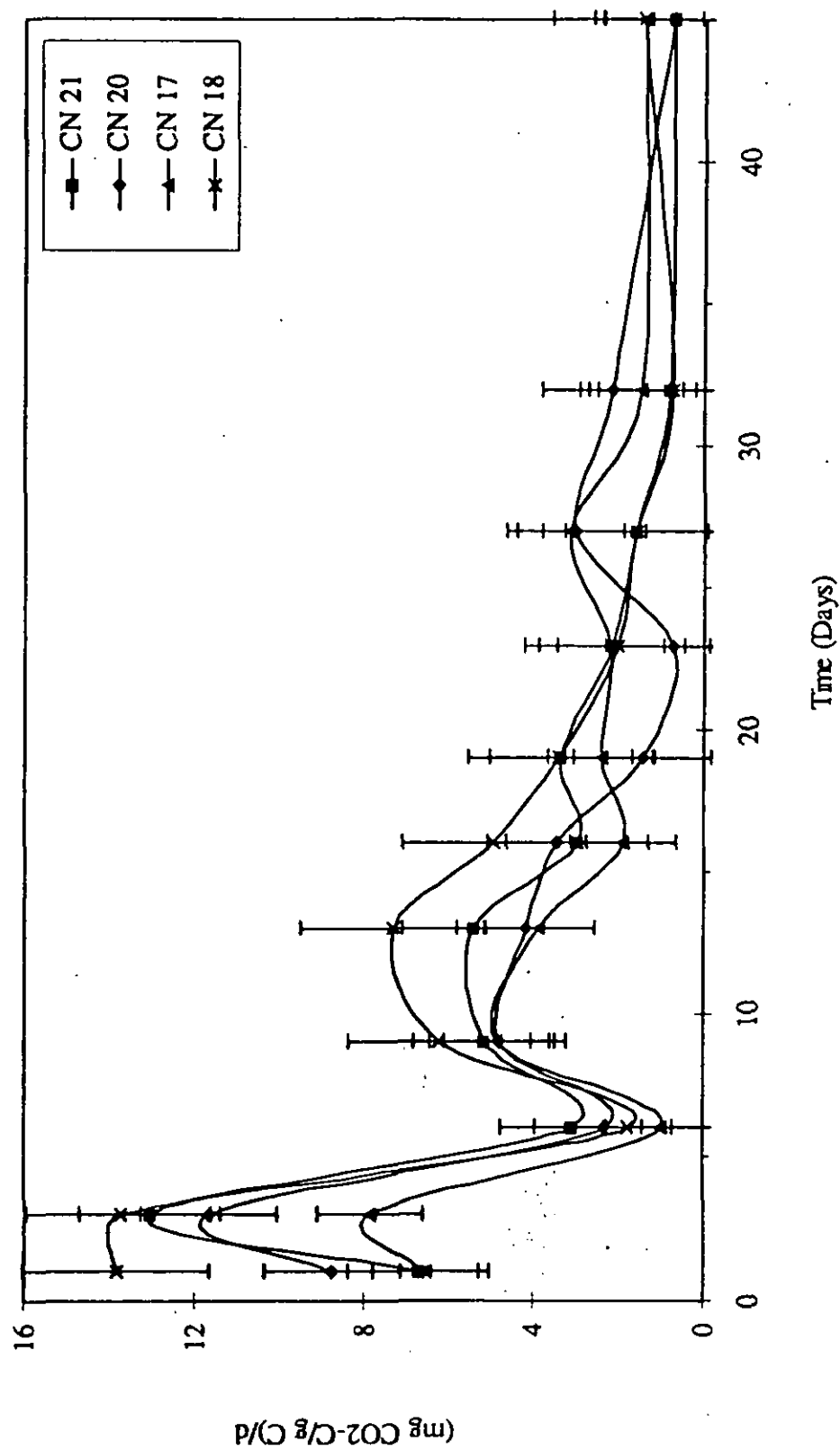


Figure 31. Mean compost CO<sub>2</sub> production rate versus time (days) for the four treatments during phase III.

the final period of composting. CO<sub>2</sub> production variation was comparable for all treatments, due to the establishment of similar microbial populations. Final CO<sub>2</sub> evolution rates were less than 4 (mg CO<sub>2</sub>-C/g C)/day for all phases, implying a stable compost for all treatments.

## CONCLUSIONS

Biodegradability analysis conducted in this experiment showed that rice hulls and crawfish residuals can be composted when initial C:N ratio is within 11-42; however, mixtures containing a higher percentage of crawfish residuals to rice hulls or recycled product, tend to degrade at a faster rate. The results also showed that the initial C:N ratio is not a good indicator of the subsequent composting of lignocellulotic feedstock. In addition to N availability, the extent of C degradability must also be taken into account. The addition of a nitrogenous feedstock, such as crawfish residuals, to recycled compost had a positive effect in improving the degradability of the recycled compost and increasing the N concentration of the final compost product. Rice hulls, having good structural property (i.e. high porosity, low bulking density), proved to be an excellent bulking agent for composting crawfish residuals which provide readily available substrate for microorganisms. Further research is needed to quantify the degradation of lignocellulotic materials during repetitive composting with nitrogenous feedstock.

Commonly used biodegradability test such as the volatile solids concentration does not discriminate among readily, less readily, and not metabolized materials during composting. However, this test could be used as an overall indicator of biodegradability. Tests such as SOUR and CO<sub>2</sub> production rate are preferable for direct measurement of compost activity as well as an indication of the extent of the composting process.

## REFERENCES

- American Public Health Association (APHA), American Water Works Association, and Water Pollution Control Federation. 1992. Standard methods for the examination of water and wastewater. 18th edition. APHA, Washington, D.C.
- Crawford, S. L. 1976. Microbial degradation of lignocelluloses: The lignin component. *Applied Environmental Microbiology*, 31:714-717.
- Feldman, K. 1995. Stability index determination. *Biocycle*, 36(11):68-69.
- Garcia, C., T. Hernandez, and F. Costa. 1991. Changes in carbon fractions during composting and maturation of organic wastes. *Environmental Management*, 15(3):433-439.
- Haug, R. T. 1993. *The practical handbook of compost engineering*. Lewis Publishers, Boca Raton, Florida.
- Iannotti, D. A., T. Pang, B. L. Toth, D. L. Elwell, H. M. Keener, and H. A. J. Hoitink. 1993. A quantitative respirometric method for monitoring compost stability. *Compost Science and Utilization*, 1(3):52-65.
- Lu, N., J. H. Edwards, and R. H. Walker. 1997. Ionic activity in soil solution as affected by application of newsprint and nitrogen sources. *Compost Science and Utilization*, 5(2):68-83.
- Mizuki, E., S. Okumura, H. Saito, and S. Murao. 1993. Formation of silicon carbide from rice husks using enzymatic methods for carbon control. *Bioresource Technology*, 44:47-51.
- Regan, R. W. and J. S. Jeris. 1970. A review of the decomposition of cellulose and refuse. *Compost Science*, v. 11, January/February, 17-20.
- Rynk, R. 1992. On-farm composting handbook. NRAES-54, Northeast Regional Agricultural Engineering Service, Ithaca, NY.
- Shuler, M. L. 1980. *Utilization and recycle of agricultural wastes and residues*. CRC Press, Boca Raton, Florida.

## PART IV: OBJECTIVE 4

*(NOTE: A manuscript has been prepared describing this objective and is ready for submission to the Journal of Compost Science & Utilization. A copy is included as Attachment B).*

### JUSTIFICATION

Leachate and rainfall runoff management from fish and crustacean waste composting constitutes a challenging problem for the processing industries. The wastes from these industries are highly putrescent and contain a large amount of water. Moisture content ranges of 1.5- to 4.0-g/g solids are common (Brinton and Seekins 1988). If not properly managed, leachate from the compost can create foul odors, attract flies or otherwise be aesthetically unacceptable (Frederick et al. 1989).

Windrow composting is a widely accepted practice for aerobic decomposition of many types of organic wastes. However, substantial nutrients are lost in the leachate and runoff from these activities, potentially creating an environmental hazard (Ballesteros and Douglas, 1996; Kovacic, et al. 1992). Characterizing the leachate of a compost operation is required by permitting agencies and is necessary when considering site design parameters (Andree, 1991). Potential leachate problems could trigger fines or closures by permitting agencies.

Few techniques have been demonstrated for reducing leachate from compost, however, it is common practice to utilize materials with high moisture absorbency characteristics such as peat and sawdust, when composting fish waste to reduce leachate generation (Brinton and Seekins, 1988). Straw has been found effective for reducing nitrogen leaching losses when added to compost (Ulén, 1993). Other effective materials include cotton gin trash, hay, and bagasse (a byproduct of the sugar industry). Moisture absorption to reduce leachate also has the effect of reducing inorganic nutrient losses.

Traditional leachate and runoff management approaches include storage and/or land application or discharge into a public sewer system. Another option is to recycle the leachate by applying it to active compost piles for moisture control. This reduces the reliance on rainfall and the need

for alternative water sources. This option has not received much attention. In order to address this option it is necessary to thoroughly characterize leachate from seafood waste compost. For the purposes of this study, the seafood waste studied was limited to crawfish processing wastes. Specific objectives were to:

- 1) characterize the leachate from composting crawfish waste
- 2) quantify the nutrient losses from the system
- 3) examine the potential benefits of recycling the leachate to the compost pile.

## MATERIALS AND METHODS

Small windrows were constructed on an impermeable polyethylene liner bed over sloping (5:1) ground. The windrows each measured 3.0 x 1.5 x 1.5 m (Fig. 32). Three windrows were constructed:

- 1) the first receiving recycled leachate (RL),
- 2) the second receiving tap water (W)
- 3) the third is the control which received rainfall only.

The feedstocks for each windrow consisted of 150 kg (wet weight) of crawfish wastes and 150 kg (wet weight) of rice hulls. The bulk density, organic carbon (C) and total nitrogen (N) concentrations, and moisture content of these materials were determined prior to use (Table 10). Leachate from underneath the windrow and runoff from the same windrow were collected into one single tank (300-L). Stored leachate/runoff or tap water was occasionally added to the corresponding windrow to maintain adequate moisture content. The windrows were turned manually 19 days and 30 days after initially blending the

Table 10. Characteristics of rice hulls and crawfish residuals.

Material	Moisture <sup>1</sup> Content %	Bulk <sup>1</sup> Density (kg/m <sup>3</sup> )	Organic-C ----- (g/kg solids) -----	Total-N	C:N
Rice hulls	9.8	104.4	372.0	4.8	76.9
Crawfish	66.2	466.4	317.3	50.3	6.3

<sup>1</sup> Wet basis

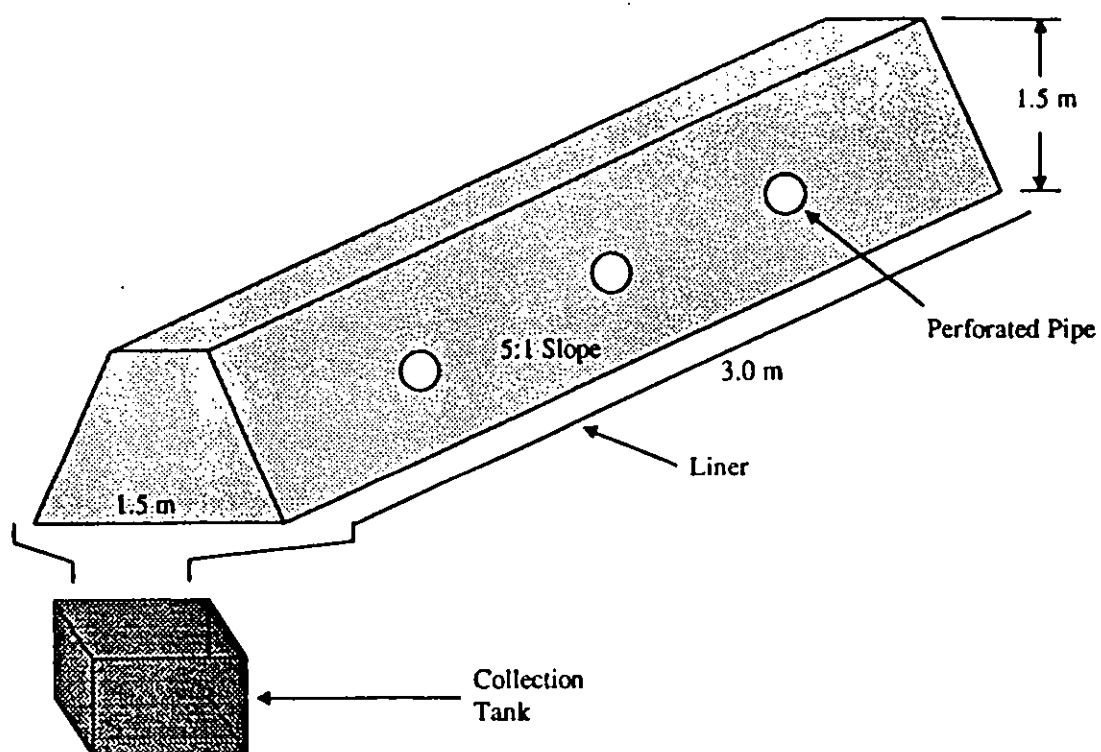


Figure 32. Research windrow with leachate collector system.

material. Passive aeration was provided by three perforated PVC pipes (25-mm diameter) positioned laterally across each windrow. Oxygen concentration measurements showed that passive aeration was adequate to maintain aerobic conditions throughout the composting period.

Leachate/runoff samples from the windrows were collected after each rainfall or watering event. Triplicate leachate/runoff samples were analyzed for pH, chemical oxygen demand (COD), nitrate ( $\text{NO}_3$ ), ammonium ( $\text{NH}_4$ ), and primary elements. Three samples (~50 g each) were collected twice weekly from each windrow at different locations. Compost samples were analyzed for moisture content, volatile solids, organic C, total N,  $\text{NO}_3$ ,  $\text{NH}_4$  and primary elements. Compost temperature was measured with copper-constantan thermocouples at four equally spaced locations and connected to CR7 datalogger (Campell Scientific, Logan, UT). Percent oxygen in the compost airspace was measured three times weekly using a Model OT-21 oxygen probe (Demista Instruments, Wheeling, IL).

Compost moisture content was determined twice weekly by the gravimetric method (APHA et al., 1992). After drying, samples were ground (150 mesh), thoroughly mixed and stored in an airtight containers. Approximately 5-g sub-samples were combusted at  $550^\circ\text{C}$  to determine volatile solids content. Approximately 20-mg sub-samples were used for organic C and total N determination using a Heraeus model CHN-O Rapid Analyzer. Compost  $\text{NO}_3$  and  $\text{NH}_4$  concentrations were determined in KCl extracts (1:10) using a Wescan Model 360 Analyzer (Wescan Instrument Inc., Deerfield, IL), along with the leachate/runoff  $\text{NO}_3$  and  $\text{NH}_4$  concentrations. Leachate/runoff pH was measured in-situ with a Digi-Sense 5939-10 digital meter (Cole-Parmer Instrument Co., Niles, IL). Leachate/runoff COD was determined by the titrimetric method (APHA et al., 1992) using accu-TEST™ vials (Bioscience, Inc., Bethlehem, PA). Approximately 500-mg of ground compost were digested with 16 N nitric acid for elemental analysis. Elemental analysis of compost extract and leachate/runoff were determined by the Inductively Coupled Plasma (ICP) method (APHA et al., 1992).

## RESULTS AND DISCUSSION

Moisture content remained in the optimum range (35- to 60%) during most of the composting process for RL and W windrows but not for control



(Fig. 33). Because rice hulls do not retain water well, it was not until the crawfish started to degrade where the moisture content was well retained over 0.7-g/g solids (after 15-days). Although the moisture content for the control was not in the optimum range, this mixture experienced similar temperature profile to the other mixtures (Fig. 34). Initially, during the first week, all windrows experienced high temperature ( $>45^{\circ}\text{C}$ ), then, temperatures started to drop gradually to near the ambient temperature suggesting that the composting process has slow down (after 39-days).

During composting, volatile solids content tends to decrease due to microbial degradation of organic matter and production of carbon dioxide. For the control and W windrows, the volatile solids content decreased gradually through out the composting process (Fig. 35). However, for the RL windrow, the volatile solids decreased continuously until 19-days where the addition of leachate/runoff led to an increase in volatile solids. Although the addition of the organic matter contained in the leachate/runoff resulted in an increase in volatile solids, however, on day 30, the RL windrow contained 59.5% volatile solids compared to 64.6 and 66.0%, respectively, for the W and control. It is then recommended that leachate/runoff addition be adopted only during the early period of high microbial activity. Organic C content was reduced from an initial value of 394-g/kg to final value of 351-, 348-, and 362-g/kg for RL, W, and control, respectively (Table 11). Final organic C was the highest for the control since the crawfish waste was not completely degraded.

Table 11. Carbon, nitrogen, ammonium and nitrate concentrations, and C:N ratios in initial and final compost from three windrows under three water regimes<sup>1</sup>. Values are means of three replicates.

Property	Units	Initial	Final			LSD <sub>0.05</sub> <sup>2</sup>
			L	W	R	
Organic-C	g/kg solids	394.2	351.1	348.4	362.5	1.5
Total-N	g/kg solids	15.8	9.2	8.9	11.2	0.4
C:N	--	24.9	38.2	39.1	32.4	11
NH <sup>4</sup> -N	mg/kg solids	280.6	43.4	48.4	330.4	54
NO <sup>3</sup> -N	mg/kg solids	34.2	156.7	156.8	47.4	23

1 L = watered with leachate recycled from pile; W = Watered with tap water; R = unwatered except for rainfall.

2 Least significant difference.

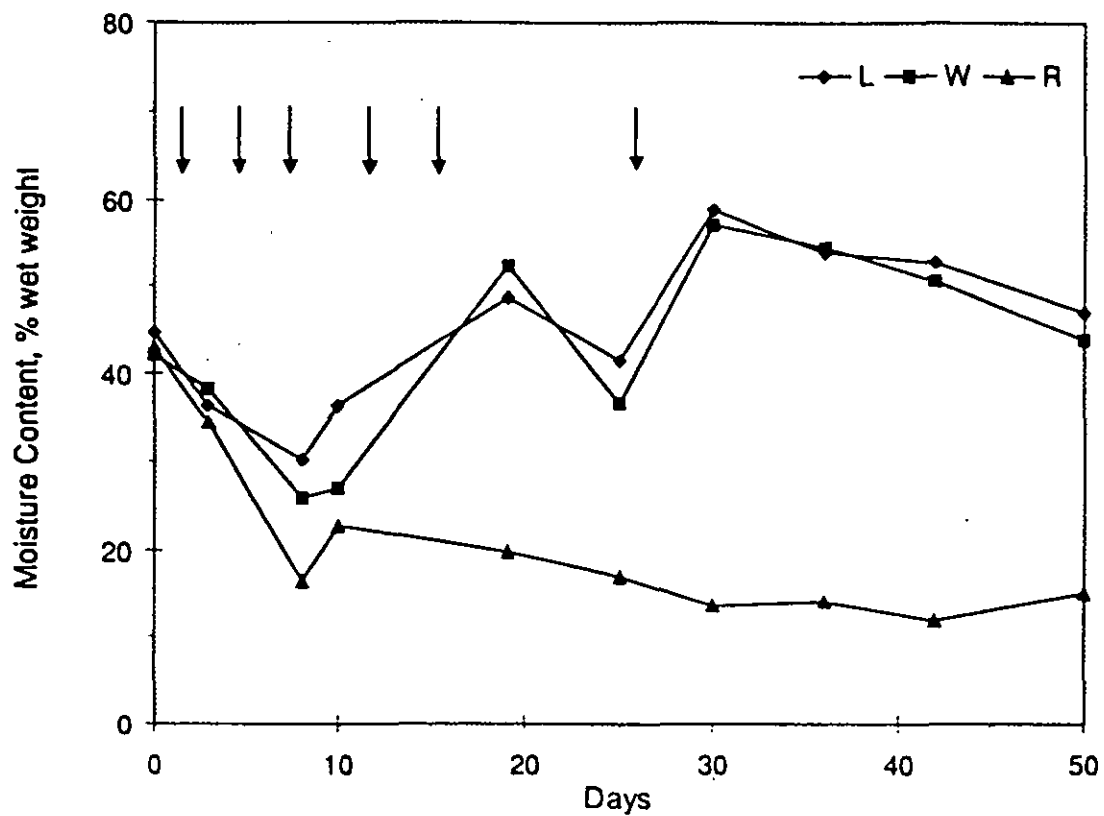


Figure 33. Moisture content of compost during the 50-day study period. Arrows represent the times when the leachate/runoff or tap water were added to moisten the L and W windrows. L = watered with leachate; W = watered with tap water; R - unwatered except for rainfall.

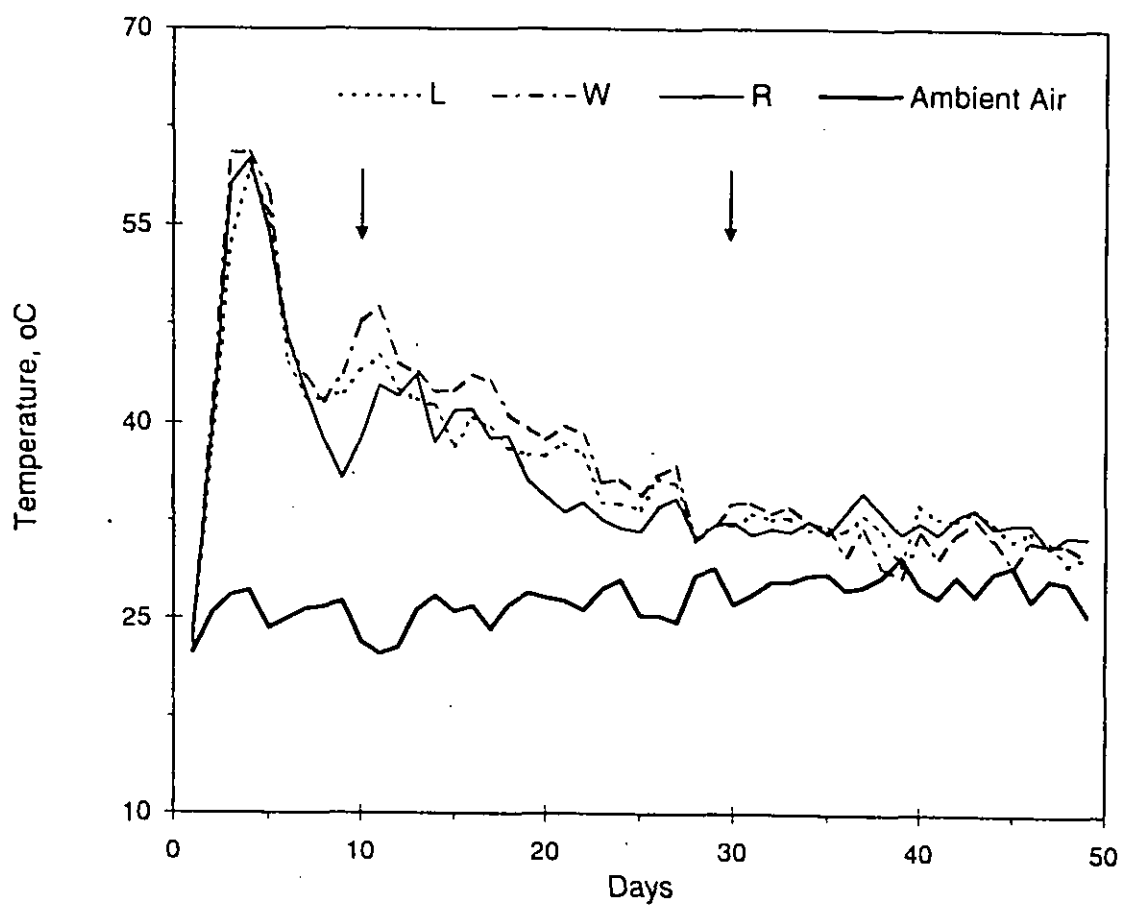


Figure 34. Mean compost and ambient air temperatures. Arrows represent the times when the windrows were turned. L = Watered with recycled leachate; W = watered with tap water; R = Unwatered except for rainfall.

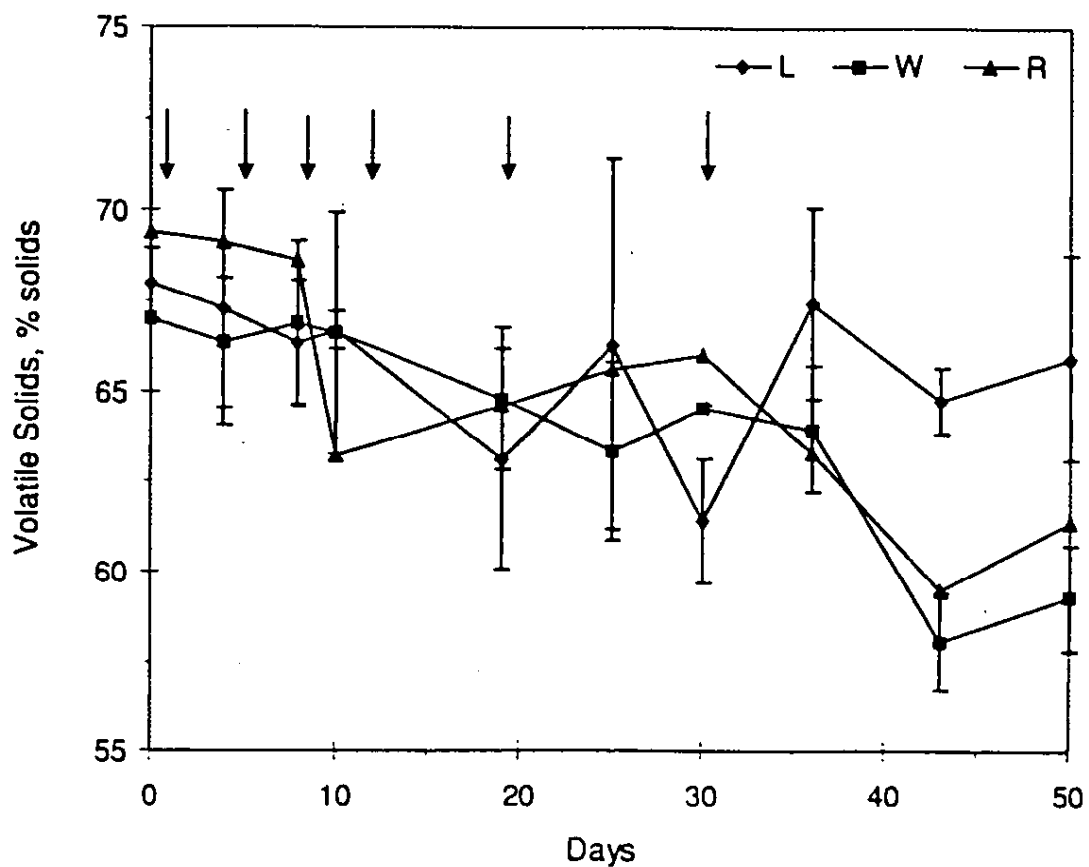


Figure 35. Change of volatile solids content of compost during the 50-day study period. Arrows represent the times when the leachate/runoff or tap water were added to moisten the L and W windrows. Error bars are the standard deviations. L = watered with leachate; W = watered with tap water; R = unwatered except for rainfall.

Final total-N,  $\text{NH}_4$ , and  $\text{NO}_3$  concentrations were comparable for RL and W windrows (Table 11). Total N was reduced from an initial value of 15.8-g N/kg to 9.2- and 8.9-g N/kg for RL and W, respectively. For control, total N was reduced only to 11.2-g N/kg. Final compost  $\text{NO}_3$  was much higher for RL and W windrows (~157-mg  $\text{NO}_3\text{-N}$ ) than control (47.4-mg  $\text{NO}_3\text{-N}$ ) indicating that this compost have not fully decomposed. The RL windrow had slightly higher total N and organic C content than the W windrow.

Because of the increase in volatile solids for RL at the end of the compost period and the small concentration of elemental constituents, it is apparent to compare the change in elemental content on a volatile solids free basis (i.e. ash basis). Percentage losses of all measured compost elements (Mg, Mn, Na, Ca, K, P and S) were less for the RL than the W windrow (Table 12). For example, K losses from the W windrow was 29% and only 4.3% for the RL windrow. Phosphorous losses were 10.6% from the W windrow, however, RL windrow showed a slight increase of 4.0%.

Table 12. Initial and final concentrations of principal nutrients (g/kg solids) for the three windrows<sup>1</sup>.

Element	Initial	Final			LSD <sub>0.05</sub> <sup>2</sup>
		L	W	R	
Mg	0.78	0.95	0.94	0.97	0.22
Mn	0.24	0.25	0.28	0.24	0.04
Na	1.29	1.44	1.45	1.48	0.33
Ca	32.1	42.1	44.3	47.4	4.62
K	2.98	3.05	2.71	2.94	0.19
P	2.19	2.43	2.50	2.66	0.80
S	1.48	1.35	1.35	1.44	0.29

1 L = watered with recycled leachate; W = Watered with tap water;  
R = Unwatered except for rainfall. Values are means of three replicates.

2 Least significant difference.

For all windrows, leachate/runoff pH had a rapid increase from pH 6.8 on the first day to pH 9.2 on the fifth day (Fig. 36). This initial rapid pH increase is due to ammonification and its role as a proton sink (Miller, 1992). The pH then fluctuated between pH 8 and 9 for the next 10 days.

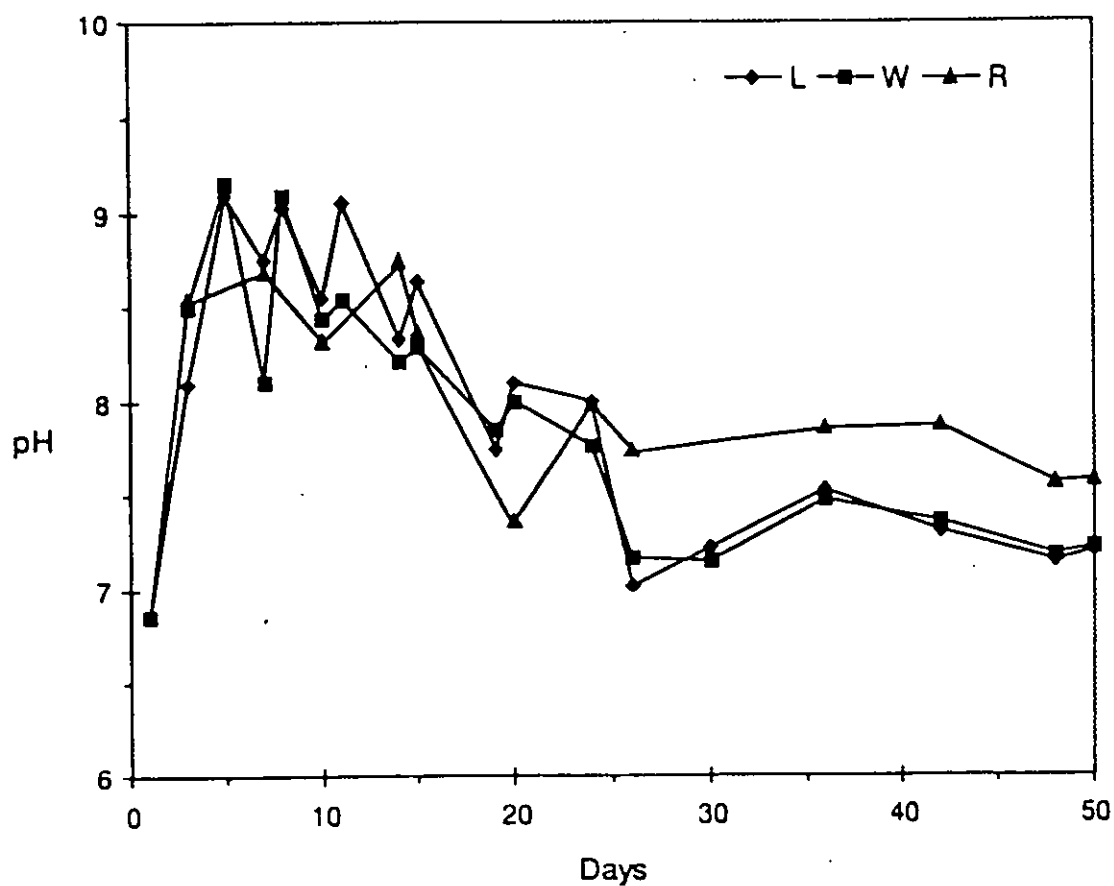


Figure 36. Leachate/runoff pH from the L, W and R windrows during the 50-day study period. L = watered with leachate; W = watered with tap water; R = unwatered except for rainfall.

Final pH was 7.2 for RL and W, and 7.5 for the control.. Ammonium losses in leachate/runoff was elevated especially during the high rate of the composting process (first 25 days) and totaled ~22-g  $\text{NH}_4\text{-N/kg N}$  (347-mg  $\text{NH}_4\text{-N/kg solids}$ ) of the original mixture from each of the W and control windrows over the 50-day period (Fig. 37). Ammonium concentration reached a maximum value of 190.6-mg  $\text{NH}_4\text{-N/L}$  on day 14. Nitrate losses were fairly distributed for the W windrow over the 50-day period (Fig. 38). Nitrate total losses amounted to 2.23- and 1.33-g  $\text{NO}_3\text{-N/kg N}$  (35.8- and 21.3-mg  $\text{NO}_3\text{-N/kg solids}$ ) for the W and control windrows, respectively. Nitrate maximum concentration was reached on day 36 (38.8-mg  $\text{NO}_3\text{-N/L}$ ) for the W windrow. Ballesterro and Douglas (1996) found that  $\text{NO}_3\text{-N}$  in soil water could reach as high as 900-mg  $\text{NO}_3\text{-N/L}$  at 1.5-m below the farm waste compost windrow. They also determined that the farm waste lost 230-g total N/kg compost initially present over the 60-day study period. Ulén (1993) found that an average of 48.8-g total N/kg N initially present were leached over a seven month winter experiment from straw and manure compost.

Phosphorous is the major nutrient in runoff related to surface water quality. Excessive loading would contribute to eutrophication. Soluble-P losses were generated mainly in the first 25-days for the W windrow (Fig. 39). Over the 50-day period, total soluble-P losses amounted to 62-mg P/kg solids and reached a maximum concentration of 46.6-mg P/L on day 19. Ulén (1993) observed mean losses of 24-g P/kg P in winter compost leachate and a typical total-P concentration of 50-mg/L in runoff from straw and manure compost. Also, COD loading were mainly during the first 25-days for the W windrow (Fig. 40). Chemical oxygen demand had reached a maximum concentration of ~4,500-mg/L on day 19 in leachate/runoff water from the W windrow. Total load of COD was 11.2- and 9.3-g COD/kg C (4.4- and 3.6-g COD/kg solids) of the initial compost from the W and control windrow respectively.

## CONCLUSIONS

Results have shown excessive loss of nutrients in leachate and runoff water. The reuse of leachate/runoff could provide a compost richer in nutrients and save water need at the same time reduce the potential environmental impacts of composting facilities from excessive nutrients losses in surface and subsurface water or additional wastewater treatment. Further research is needed to characterize leachate and runoff in various

environmental and weather conditions. Nutrient retention from the leachate/runoff reuse needs to be investigated further for different feedstocks. Characterizing the leachate and runoff will provide valuable information for design of compost facilities.



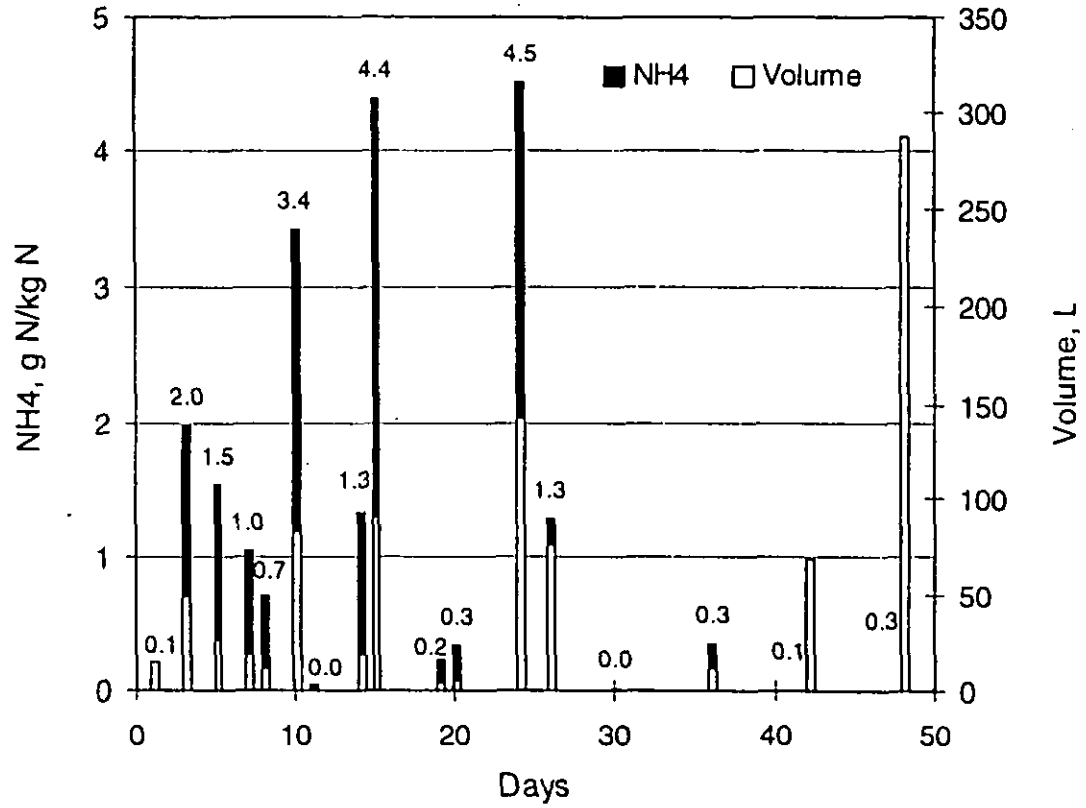


Figure37. Ammonium losses in leachate/runoff from the windrow watered by tap water expressed in g/kg Total-N of the initial compost dry mass.

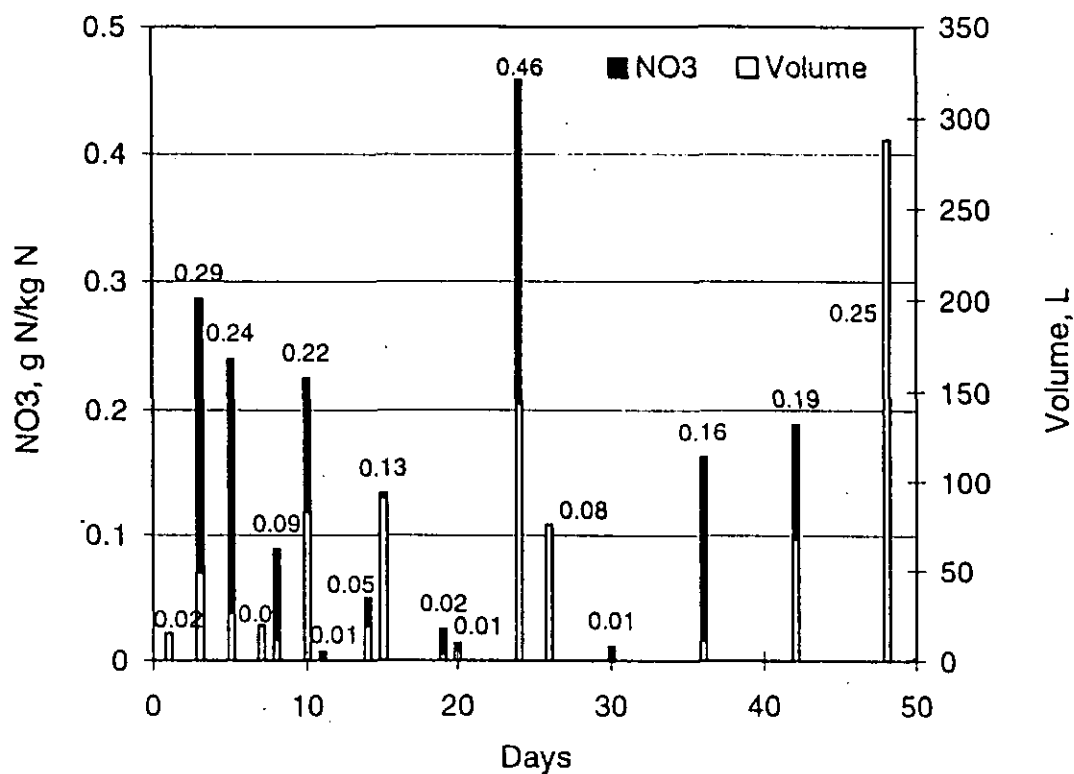


Figure 38. Nitrate losses in leachate/runoff from the windrow watered by tap water expressed in g/kg Total-N of the initial compost dry mass.

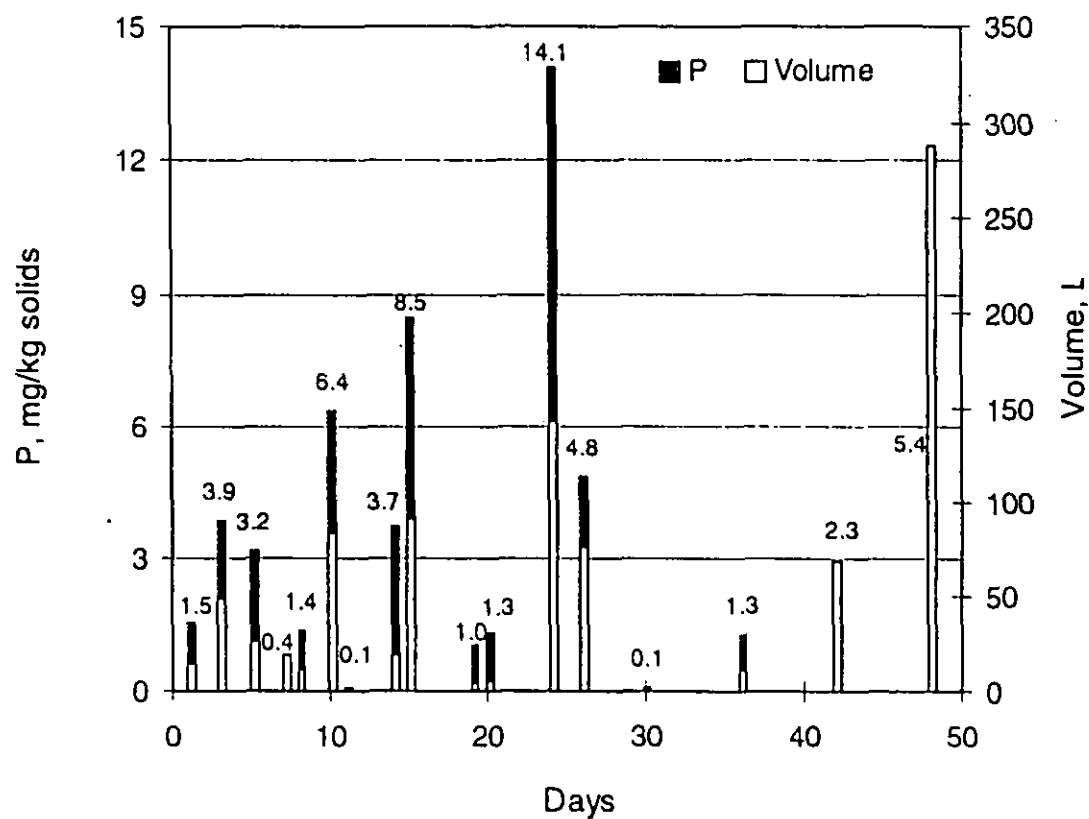


Figure 39. Phosphorus losses in leachate/runoff from the windrow watered by tap water expressed in g/kg of the initial compost dry mass.

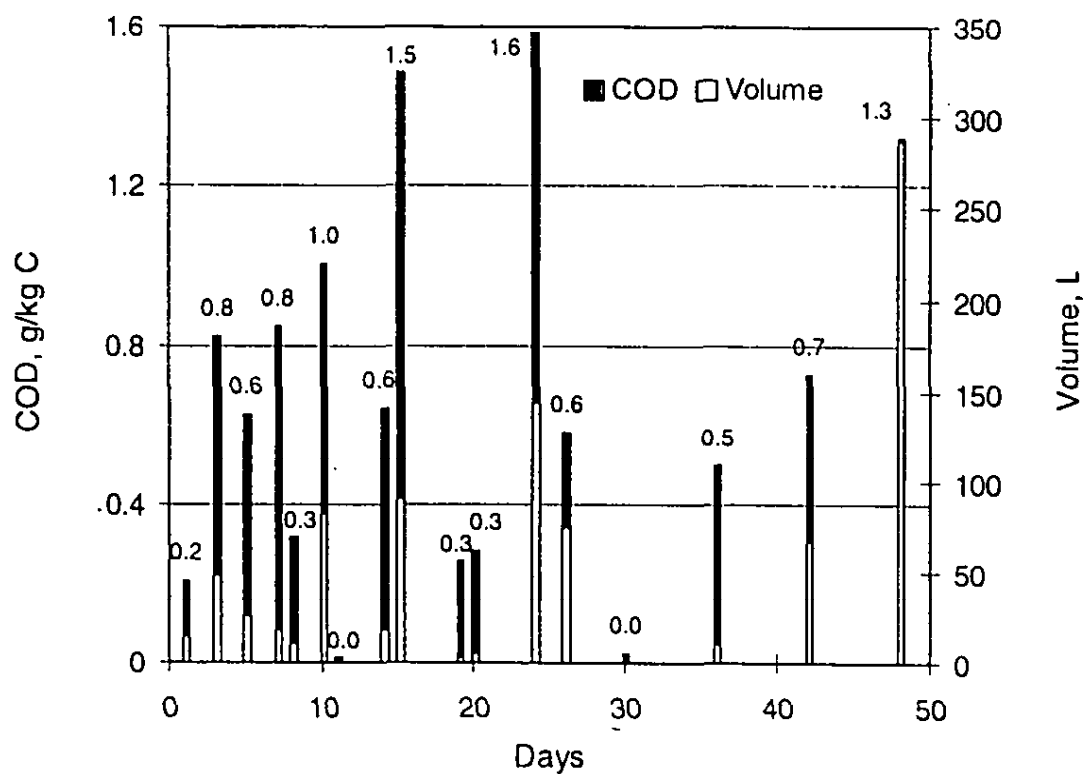


Figure 40. Organic carbon losses in leachate/runoff from the windrow watered by tap water expressed as chemical oxygen demand (COD) in g/kg carbon of the initial compost dry mass.

## REFERENCES

- American Public Health Association (APHA), American Water Works Association, and Water Pollution Control Federation. 1992. *Standard Methods for the Examination of Water and Wastewater*. 18th edition. APHA, Washington, D.C.
- Andree, S. 1991. Implementing fisheries by-products composting applications: The next step. *Proceedings of the 1991 Fisheries By-Products Composting Conference*. Madison, WI.
- Ballesteros, T. P. and E. M. Douglas. 1996. Comparison between the nitrogen fluxes from composting farm wastes and composting yard wastes. *Transactions of the ASAE*. 39(5): 1709-1715.
- Brinton, W. F. and M. D. Seekins. 1988. Composting Fish By-Products: A Feasibility Study. Time & Tide RC & D, Waldodoro, ME.
- Frederick, L., R. Harris, L. Peterson, and S. Kehrmeyer. 1989. The Compost Solution to Dockside Fish Wastes. WIS-SG-89-434. University of Wisconsin Sea Grant Advisory Services, Madison, WI.
- Kovacic, D. A., R. A. Cahill, and T. J. Bicki. 1992. Compost: Brown gold or toxic trouble? *Environmental Science and Technology*. 26(1):3841.
- Miller, F. C. 1992. *Composting as a Process Based on the Control of Ecologically Selective Factors*. p. 514-544 In: *Soil Microbial Ecology* by F. B. Metting, Jr. editor., Marcel Dekker, New York.
- Ulén, B. 1993. Losses of nutrients through leaching and surface runoff from manure-containing composts. *Biological Agriculture and Horticulture*. 10:29-37.

## PART V: OBJECTIVE 5

### JUSTIFICATION

The Louisiana State University Agricultural Center operates a compost research/teaching/training facility at its Ben Hur Research Farm in Baton Rouge. Plans are nearing completion to replace the old 2.2 acre facility with a new 8 acre facility (Attachment C, appearing in *Agricultural Center News*, July, 1998.). The facility, in use for approximately six years, is used by Agricultural Center research faculty as well as Louisiana Cooperative Extension Service personnel who use the facility to conduct training classes and result demonstrations to the agricultural sector. The facility is equipped with tub grinders, trommel screens, shakers, spreaders, windrow turners and front-end loaders.

LSU Ag Center scientists have been conducting research on the best ways to create compost and are sharing the results with compost facility operators in a semi-annual training school which has gained national and international recognition (Attachment D, appearing in *LSU Today*, July, 1998). Both Drs. Breitenbeck and Lawson have been instructors at the school since its inception. Information and results of the fish compost project were distributed to students at the school in the fall of 1996, spring and fall 1997, and spring 1998.

A former student at the compost training school, Mr. Irvin Richoux, the superintendent of public works and street commissioner for Grand Isle, Louisiana, a Gulf coastal island community in south Louisiana. As a result of his training at the school, Mr. Richoux and LSU researchers and extension personnel collaborated on a project to bring commercial scale composting to Grand Isle. The residents of Grand Isle have long been plagued with the problem of disposing of large amounts of fish and seafood processing residuals, since Grand Isle is an old commercial and recreational fishing community. The old concept was to discard the residuals into the nearest waterway. However, with environmental regulations becoming more stringent in the recent past, this is no longer an option. Since Mr. Richoux was trained in compost facility operation, he brought the idea of composting to the residents of the island. They at first purchased several dozen commercially manufactured home-sized compost units, but these proved to be too small for the amount of wastes being composted.

## MATERIALS AND METHODS

LSU researchers designed and fabricated two three-bin compost units identical to those depicted in Figures 13 and 14 and erected the composters at two sites on Grand Isle in June, 1998. One was located next to the Wayne Estay Shrimp Company and received the shrimp heads and shells from peeling operations. The other composter was located behind the Cajun Holiday Motel. This site received the finfish residuals from the motel's fish cleaning station. In both instances, rice hulls were used as the bulking agent in combination with the fish residuals.

## RESULTS AND DISCUSSION

A serious impediment to managing this project was the distance of the site from the LSU campus. Grand Isle is a 3-hour one-way drive from the campus. This limited the number of visits that LSU researchers could visit the site. Consequently, it was necessary for the researchers to rely on local personnel to manage the compost units. This did not always prove to be successful. The compost units functioned very well considering the conditions, however, it quickly became apparent that they were too small for the amount of wastes being added on almost a daily basis. Another problem was lack of management. The shrimp plant owner and motel operator did not always have the time required to devote to management of the compost unit at his site. As a result, bulking agent was not delivered in large enough quantities when required. The compost became too dry from lack of water and flies and odors were a problem. All of these problems are solvable by closer management.

Since the original composters proved to be too small, larger units were designed with additional features. The sides of the units were constructed with 1/4-inch mesh plastic fabric cloth in order to allow more oxygen to enter the compost from the sides. Was to achieve better decomposition with less odor problems. No design drawings or photographs of this new composter are available at the time of this writing.

A simple compost handbook (see Attachment F) was produced and distributed to Mr. Richoux in order that he may distribute them to interested

parties at Grand Isle. Workshops were planned in September but both were cancelled due to tropical storm action in the area. Another workshop is planned for the spring season of 1999.



## **ATTACHMENT A**

## Cocomposting of Crawfish and Agricultural Processing By-Products

M. Y. Minkara, T. B. Lawson, G. A. Breitenbeck and B. J. Cochran  
Louisiana State University Agricultural Center, Baton Rouge, Louisiana

Disposal of crawfish processing residuals (hereinafter, referred to as crawfish residuals) poses a challenging problem to the rapidly expanding crawfish industry. Cocomposting is examined as a waste management alternative to landfill disposal. Four agricultural processing by-products were evaluated for use as bulking agents in composting crawfish residuals: wood chips, rice hulls, bagasse, and bark. Approximately 5 to 6.5 volumes of each bulking agents were mixed with one volume of crawfish residuals in 0.3-m<sup>3</sup> composting reactors. Compost temperature was continuously monitored, and moisture content was maintained within a desirable range. Samples were collected twice weekly throughout the 50-d composting process. Use of bagasse as a bulking agent led to the largest reduction in volatile solids (27.6 percent), organic C (55.3 percent), particle size (64.7 percent), and compost volume (52.8 percent). Finished compost using bagasse contained the greatest concentration of N (18.4 g N/kg and 160 mg NH<sub>4</sub>-N/kg). Self-heating patterns and decomposition of crawfish residuals were satisfactory using all four bulking agents, and no odor, insect or other nuisance problems were detected. The finished products of all compost mixtures were suitable for use as mulch or reuse as bulking agents.

### Introduction

Crawfish production is a rapidly expanding industry in the world especially in southern United States and China (U.S. Department of Commerce 1996). Louisiana is the principal crawfish producing state with 43,800 metric tons (MT) of crawfish, in 1995 (Louisiana Cooperative Extension Service 1995). Only the tail meat of this crustacean is consumed, while the exoskeleton and intestines are discarded. Because only 15 to 20 percent of whole crawfish is edible, more than 35,000 MT of processing residuals are discarded annually. Crawfish shells are rich in chitin, a natural polymer of amino sugars. Crawfish residuals are highly putrescent and readily attract insects and vermin. When left to decay on the ground, they generate an organic leachate that can pollute surface and ground water. These characteristics render the current practice of landfill disposal unsatisfactory. Composting of crawfish residuals is potentially a practical and environmentally sound disposal alternative.

Unless crawfish residuals are blended with an appropriate bulking agent, piles of these materials rapidly become anaerobic and generate noxious odors. A suitable bulking agent provides sufficient porosity for air exchange, absorbency for moisture retention and odor filtration, and favorable thermal properties. Bulking agents that serve as substrate for the microorganisms responsible for organic decomposition may stimulate initial self-heating. Costs and regional availability of suitable materials usually dominates their use as bulking agents. Many agricultural processing by-products such as wood chips, rice hulls, bagasse and bark are produced in large volumes in areas commonly used for crawfish production. In Louisiana, about 170 thousand MT of rice hulls (rice mill by-product), 1.2 million MT of bagasse (sugar cane mill by-product), and 4.3 million MT of wood by-products (including bark, wood chips and sawdust) are generated annually (Kleit *et al.* 1994). A portion of the volume of these by-products is used as biomass fuel, but their heat index values are sometimes marginal for this use.

3-15.  
R.H. and D.  
ASA-SSSA,  
sludge co-  
e proteins as  
ing agents  
transforma-  
fish farm-  
fertilizante  
so Interna-  
In:Page,  
es Agron-  
ey (Eds.)  
son, Wis-  
ural Engi-  
per pulp

Despite a few other limited uses, large volumes of these materials are available at low cost for recycling as bulking agents for composting.

The objective of this study was to assess the potential of composting crawfish residuals using four materials (wood chips, rice hulls, bagasse, and bark) as bulking agents. Several physical and chemical characteristics of compost mixtures were monitored to compare the efficacy of the composting process and the quality of final products.

### Materials And Methods

Crawfish residuals were cocomposted with each of the four bulking agents for 50 days in 0.3-m<sup>3</sup> commercially available reactors fabricated from recycled plastic (Barclay Recycling Inc., Ontario, Canada). Crawfish residuals were mixed 1:5 v/v with pine wood chips and rice hulls and 1:6.5 v/v with bagasse and bark (pine and cottonwood) (Table 1). Three replicates of each mixture having 0.3 m<sup>3</sup> volume were made. The bulk density, organic carbon (C) and total nitrogen (N) concentrations, and moisture content of these materials were determined prior to use (Table 2).

Compost temperature was measured using copper-constantan thermocouples connected to a CR7 Datalogger (Campbell Scientific, Logan, UT). Thermocouples were positioned at three equally-spaced depths (d) of the height (H) of the mixture in the center of each reactor (Figure 1). The mean height of compost in each reactor was measured twice weekly for volume reduction determination prior to collecting samples. Approximately 150 g samples from each of the 12 reactors were collected for analysis. Data reported are the means of three replicates. Samples were initially used for gravimetric determination of moisture content (APHA *et al.* 1992). Particle size, after drying, was determined by screening each sample through a series of sieves vibrating for

5 min. Sieve opening sizes were 25.4, 12.7, 9.5, 6.4, 2.36, 1.65, 0.83, and 0.59 mm. To facilitate comparisons, the mean particle size was calculated using the percentage weight of material retained by different sieves. After sieving, samples were ground (150 mesh), thoroughly mixed and stored in air-tight containers. Approximately 5 g subsamples were combusted at 550°C to determine volatile solids content. A mixture of 1:2 w/w compost to water was used to determine pH using a Corning model 250 Ion Analy-

lyzer (Corning, NY). Approximately 20 mg subsamples were used for organic C and total N determination using a Heraeus model CHN-O Rapid Analyzer. Nitrate (NO<sub>3</sub>) and ammonium (NH<sub>4</sub>) concentrations were determined in KCl extracts using a Wescan model 360 Analyzer (Wescan Instrument Inc., Deerfield, Illinois).

TABLE 1.

Volume, mass, and carbon to nitrogen (C:N) ratios of wood chips, rice hulls, bagasse, and bark cocomposted with crawfish residuals

Mixture	Volume — (w w*) —	Mass	C:N (d w <sup>^</sup> )
Wood chips:crawfish	5.0:1	2.7:1	143.5
Rice hulls:crawfish	5.0:1	1.1:1	47.3
Bagasse:crawfish	6.5:1	1.2:1	38.5
Bark:crawfish	6.5:1	3.2:1	55.8

\* Wet weight

<sup>^</sup> Dry weight

TABLE 2.

Characteristics of bulking agents and crawfish residuals

Material	Bulk Density (kg/m <sup>3</sup> ww*)	Organic C — (g/kg dw <sup>^</sup> ) —	Total N	C:N	Moisture Content (% ww)
Wood chips	255.8	475.9	2.3	207.8	10.4
Rice hulls	104.4	372.0	4.8	76.9	9.5
Bagasse	81.4	436.3	9.3	47.0	53.4
Bark	218.5	442.8	10.7	41.2	39.2
Crawfish	466.4	317.3	50.3	6.3	66.2

\* Wet weight

<sup>^</sup> Dry weight

## Cocomposting of Crawfish and Agricultural Processing By-Products

Water was added to compost mixtures as needed to maintain moisture contents between 40-60 percent. The mixtures were turned manually 17 days and 38 days after initially blending the material in the reactors. Percent oxygen in the compost piles was measured three times weekly using a model OT-21 oxygen probe (Demista Instruments, Wheeling, Illinois). Oxygen measurements showed that the perforations on the lower side of the reactors were sufficient to maintain adequate aeration [19-21 percent  $O_2$  (v/v)] in all reactors throughout the study. A 30 cm outer layer of bulking agent was maintained during the first 17 d to serve as a biofilter for odor and nuisance control. A moderate ammonia ( $NH_3$ ) odor was evident for the first 10-14 days, and when turning the mixtures, but diminished thereafter. The outer layer proved to be effective in controlling flies, odors and other nuisances.

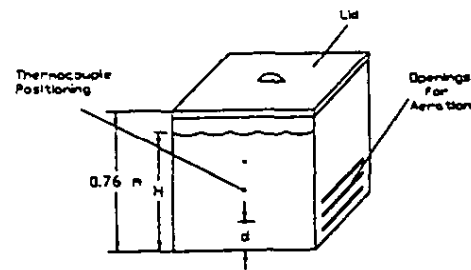


Figure 1. Description of the bench scale reactor used to cocompost crawfish residuals and four different bulking agents ( $H$  = height of mixture;  $d = H/4$ ).

## Results And Discussion

### Moisture Content, Temperature, and Volatile Solids Losses

Moisture content remained in the desirable range (40 to 60 percent) during the composting process for all mixtures except for the rice hulls which, initially, did not retain water as well as the other mixtures tested. The maximum initial moisture content obtained for a single rice hull mixture was 30 percent. After turning on the seventeenth day, moisture content consistently remained between 40 to 60 percent. Degradation of crawfish residuals apparently facilitated moisture retention by rice hulls.

Although moisture contents during the early stages of composting were not in the range typically recommended for optimal composting (Rynk 1992), rice hull mixtures achieved the most rapid self-heating and the highest initial average temperatures (Figure 2). This is possibly due to the low moisture content of this mixture which resulted in more effective heat retention. Bagasse mixtures attained the highest average tem-

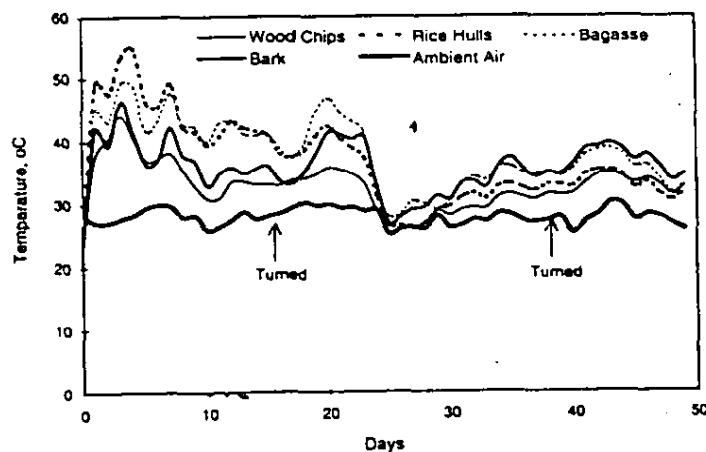


Figure 2. Variation of compost mixtures and ambient air temperatures with time (days) during the 50-day study.

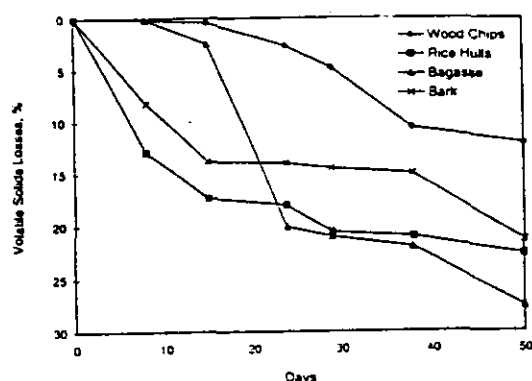


Figure 3. Compost mixtures volatile solids losses with time (days) during the 50-day study.

perature during the rest of the thermophilic period (third week). The corresponding temperature profiles of wood chip and bark mixtures were 5° to 10°C lower than those of rice hull or bagasse. After 23 d, temperatures in all reactors rapidly declined to near ambient temperature probably due to the microbial consumption of most of the readily available substrate. Thereafter, temperatures rose 2° to 15°C but remained in the upper mesophilic range (between 25° and 40°C). When the experiment was terminated after

50 d, temperatures in all mixtures were close to one another.

Over the first two weeks, rice hull mixtures had the largest reduction in volatile solids of 17.4 percent (Figure 3). This explains the initial high temperatures measured in the rice hull mixtures. After the second week, when the compost was turned, the bagasse mixtures had a sharp reduction in volatile solids (20.1 percent) which corresponded to the sudden increase in temperature. By the end of the experiment, bagasse mixtures lost an average of 27.6 percent of their initial volatile solids. Rice hull and bark mixtures lost an average of 22.6 percent and 21.3 percent, respectively, of their initial volatile solids. Wood chip mixtures lost the lowest amounts of volatile solids (12.1 percent). This explained the lowest temperature profile during the first three weeks. Rice hull and bark mixtures offered the most readily mineralizable substrate for compost microorganisms during the first two weeks of the composting process. However, bagasse and wood chip mixtures offered the most readily mineralizable substrate after the second week. Of the four bulking agents studied, bagasse offered the largest reduction in volatile solids and the maximum available substrate.

#### Changes in Organic C, Total N, and C:N Ratio

Since changes in total weight occurred during the composting process and the rate of change differed among the compost mixtures studied, comparison of concentrations of constituents expressed on a total weight basis can be deceptive. Ash weight has been used as an internal standard to demonstrate changes in constituent composition because the inorganic fraction is largely conserved during composting (Haug 1993). Change in the ratio of the weight of a constituent to that of ash, then, reflects the losses or gains of constituents relative to their initial amounts. Bagasse and bark mixtures lost an average of 55.3 percent and 49.5 percent, respectively, of their initial organic C contents on an ash basis. Not surprisingly, wood chip and rice hull

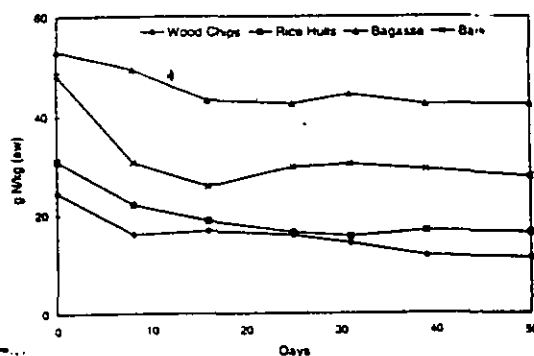


Figure 4a. Total nitrogen (g N/kg compost ash weight) concentrations versus time (days).

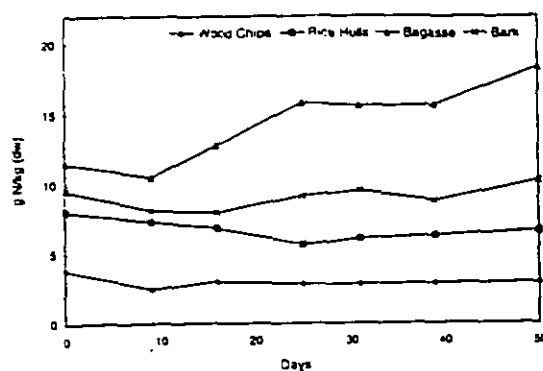


Figure 4b. Total nitrogen (g N/kg compost dry weight) concentrations versus time (days).

$\text{NH}_3$  volatilization as well as subsequent leaching of  $\text{NH}_4$  and  $\text{NO}_3$  (Soliva *et al.* 1993). Although  $\text{NH}_3$  losses were not measured, nitrogen losses are explained by changes in total N concentrations of the mixtures based on total ash weight. Nitrogen losses were clearly evident during composting crawfish residuals with each of the bulking agents (Figure 4a). Total N concentrations (ash basis) were reduced for all mixtures after 50 d composting. Composting crawfish residuals with rice hulls, bark and bagasse resulted in average losses of total N of 47.2 percent, 42.6 percent and 20.2 percent (ash basis), respectively, after 50 d. Despite the fact that wood chip mixtures had the highest C:N ratio (Figure 5) and the lowest total N concentration (Figure 4b), they showed the greatest loss of total N (53.6 percent ash basis) by the end of the experiment. On the other hand, although the bagasse mixtures had the lowest C:N ratio (Figure 5) and the highest total N concentration (Figure 4b), their N losses were minimal. Because bagasse was the most degradable of the bulking agents, a greater portion of its N may have been retained as organic N thus reducing volatile losses of  $\text{NH}_3$ . Most N losses occurred during the early stages (first 15 d) of the process, which is typical in composting (Morisaki *et al.* 1989). Total N concentration (dry weight basis) showed very little variation during the 50-d period, with the exception of bagasse mixtures (Figure 4b). Average total N concentration of bagasse mixtures steadily increased from an initial 11.5 g N/kg to a final concentration of 18.4 g N/kg after 50 d, an increase of 59.3 percent (Figure 4b). This apparent increase was more likely due to the small loss of N relative to that of total organic matter than to gains in N via biological  $\text{N}_2$  fixation or other mechanisms.

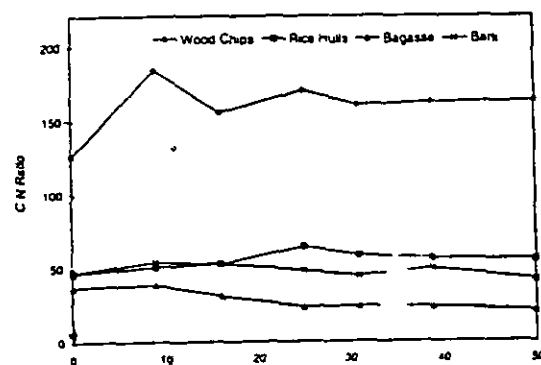


Figure 5. Variation of compost mixtures C:N ratio with time (days) during the 50-day study.

#### Ammonium, Nitrate, and pH

Initial compost pH values were about 8.4 in both rice hull and bagasse mixtures and about 7.9 in both wood chip and bark mixtures (Figure 6). Changes in pH during composting followed a similar path for all mixtures. During the first 25 d, the pH

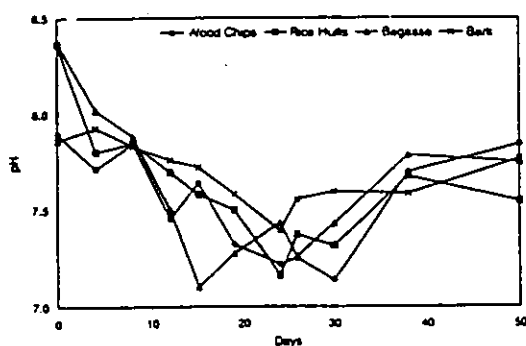


Figure 6. Variation of compost mixtures pH with time (days) during the 50-day study.

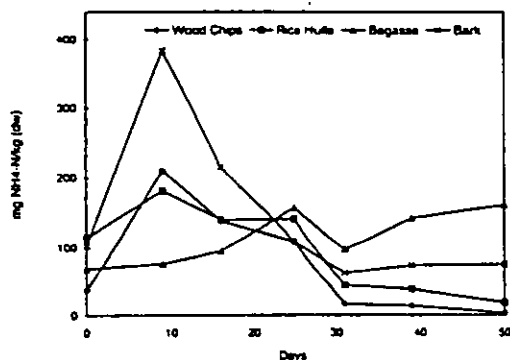


Figure 7. Ammonium (mg  $\text{NH}_4\text{-N/kg}$  compost dry weight) concentrations versus time (days).

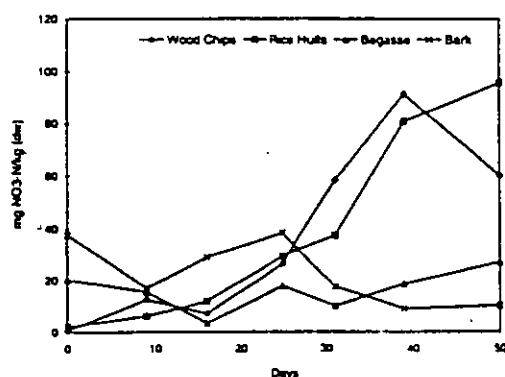


Figure 8. Nitrate (mg  $\text{NO}_3\text{-N/kg}$  compost dry weight) concentrations versus time (days).

in wood chip mixtures declined to about 17 mg  $\text{NO}_3\text{-N/kg}$  during the last 12 d of the study. Throughout the experiment,  $\text{NH}_4$  and  $\text{NO}_3$  concentrations in bagasse mixture were consistently low, which support the hypothesis that greater immobilization of N may account for the lower losses of N from bagasse mixture. Bagasse appeared to be able to assimilate mineralized N more readily than bark, rice hulls, or wood chips.

was continuously decreasing to about 7.4 for bagasse and bark and 7.2 for wood chip and rice hull mixtures. This decrease in pH is probably due to organic N mineralization and the transient appearance of volatile organic acids (Miller 1992). In the final 25 d, pH values increased to about 7.6 for rice hull, 7.8 for bagasse and bark, and 7.9 for wood chip mixtures.

During composting, microbial activities decompose organic matter and transform complex N compounds into mineral forms such as  $\text{NH}_3$ ,  $\text{NH}_4$ , and  $\text{NO}_3$ . In crawfish residuals composting, this transformation produced  $\text{NH}_4$  concentrations in the range of 10 to 400 mg  $\text{NH}_4\text{-N/kg}$  (Figure 7). Bagasse and bark mixtures maintained relatively high  $\text{NH}_4$  concentrations during the last 20 d and contained 160 mg  $\text{NH}_4\text{-N/kg}$  and 76 mg  $\text{NH}_4\text{-N/kg}$ , respectively, at the end of the composting process. Final  $\text{NH}_4$  concentrations of rice hull (18 mg  $\text{NH}_4\text{-N/kg}$ ) and wood chip mixtures (3 mg  $\text{NH}_4\text{-N/kg}$ ) were significantly lower. As heterotrophic demand for available N declines, accumulated  $\text{NH}_4$  may undergo microbial oxidation to  $\text{NO}_2$  and  $\text{NO}_3$ . During composting,  $\text{NO}_3$  concentrations in bagasse and bark mixtures remained below 40 mg  $\text{NO}_3\text{-N/kg}$  (Figure 8). However, an increase in  $\text{NO}_3$  concentrations was observed in rice hull and wood chip mixtures after 25 d. At the end of the experiment, rice hull mixtures contained the highest average  $\text{NO}_3$  concentration (97.2 mg  $\text{NO}_3\text{-N/kg}$ ). Concentration of  $\text{NO}_3$

## Particle Size and Volume Reductions

The mean particle size of organic mixtures reduces during composting due to degradation of the organic fraction. Bagasse mixtures had the greatest mean particle size reduction of 53.7 percent of the original bulking agent and 64.7 percent of the initial mixtures after 50 d (Table 3). Wood chip mixtures had the least reduction (24.2 percent) of the initial mixtures. Bark mixtures mean particle size was reduced by 45.7 percent of the initial mixtures and 37.1 percent of the original bulking agent. Rice hulls final mean particle size was 1.69 mm reduced by about 60 percent of the initial mixtures size (4.23 mm) and reduced only by 1.2 percent of the original bulking agent size (1.71 mm). All degradation of rice hull mixtures is contributed to the degradation of crawfish residuals. Rice hulls have a silicon skeleton which contribute to their recalcitrance to microbial degradation (Lalche and Nash 1983).

Volume of composted materials is reduced significantly after composting. The greatest overall volume reduction (52.8 percent) occurred in the bagasse mixtures while the least reduction (16.5 percent) occurred in the rice hull mixtures. Bark and wood chip mixtures volume reductions were 43.8 percent and 22.6 percent, respectively. The lower volume reduction of the rice hull and wood chip mixtures is due to the low degradability of the silicon and lignin contained in these materials. This could be considered an advantage in some situations where these materials could be reused as bulking agents in additional composting operations thus reducing the quantity of bulking agent required.

## Conclusions

All bulking agents evaluated in this study worked well when cocomposted with crawfish residuals. Cocomposting crawfish residuals with bagasse resulted in the greatest reductions in volatile solids (27.6 percent) and organic C (55.3 percent), as well as in total volume shrinkage (52.8 percent) and mean particle size reductions (64.7 percent). The compost derived from the bagasse mixtures contained the highest nutrient content (18.4 g N/kg and 160 mg  $\text{NH}_4\text{-N/kg}$ ). Rice hull mixtures resulted in the least total volume and mean particle size reductions, nevertheless, these mixtures maintained high  $\text{NO}_3$  concentration and lost notable amounts of volatile solids. Bark mixtures were satisfactory in terms of volatile solids losses (21.3 percent) and final N content (10 g N/kg). Wood chip mixtures did not perform as well as the other mixtures tested, nevertheless, crawfish residuals were completely decomposed during the 50-d study period.

If the goal is to produce a high quality compost, cocomposting with bagasse appears preferable. However, if the goal is to dispose of large volumes of crawfish residuals, the use of rice hulls or wood chips as a bulking agent offers an advantage in that

TABLE 3.  
Mean particle size (mm) of raw bulking agents  
and mixtures and mean particle size reductions  
after 50 days\*

	Wood Chips	Rice Hulls	Bagasse	Bark
	(Mean particle size, mm)			
Bulking agent	5.3	1.7	5.1	8.5
Initial mixture	6.2	4.2	6.7	9.9
Mixture at 50 d	4.7	1.7	2.4	5.3
Reduction of mixture at 50 d				
from bulking agent, %	11.4	1.2	53.7	37.1
from initial mixture, %	24.2	60.0	64.7	45.7

\* Crawfish residuals size ranged between 2 and 75 mm.



larger volume of crawfish residuals can be treated per volume of bulking agent. Reuse of the composted materials for additional composting of crawfish residuals could be cost effective. Using wood chips, rice hulls, bagasse, bark, or other suitable bulking agent for disposal of seafood processing residuals by composting appears to offer a practical solution. Biodegradability and nutrient retention using such by-products merit further study to optimize the compost process and to consistently produce high quality finished compost.

#### Acknowledgments

This research was supported in part by a grant from the Louisiana Department of Environmental Quality. The laboratory assistance of Mr. David Schellinger, Louisiana State University Agronomy Department, was greatly appreciated. Thanks also to Ms. Louise Braud and Mr. Jonathan Scott, Louisiana State University Biological and Agricultural Engineering Department, for their contribution in the fieldwork.

#### References

- American Public Health Association (APHA), American Water Works Association, and Water Pollution Control Federation. 1992. Standard methods for the examination of water and wastewater. 18th edition. APHA, Washington, D.C.
- Haug, R. T. 1993. The practical handbook of compost engineering. Lewis Publishers, Boca Raton, Florida, p. 317-319.
- Kleit S., C. F. de Hoop, and S. J. Chong. 1994. An overview of agriforestry waste production and use in Louisiana. Sixth National Bioenergy Conference, Reno/Sparks, Nevada.
- Lalche, A. J. and V. E. Nash. 1983. A preliminary evaluation of composted rice hulls and arkalite as components of a container plant growing medium. *Mississippi Nurseryman's Assn.* 1(4).
- Louisiana Cooperative Extension Service. 1995. Louisiana Summary, Agriculture and Natural Resources.
- Miller, F. C. 1992. Composting as a process based on the control of ecologically selective factors. In: *Soil Microbial Ecology* by F. B. Metting Jr., (ed.), Marcel Dekker, New York, p. 514-544.
- Morisaki, N., C. C. Phae, K. Nakasaki, M. Shoda, and H. Kubota. 1989. Nitrogen transformation during thermophilic composting. *Journal of Fermentation and Bioengineering*, 67(1): 57-61.
- Rynk, R. 1992. On-farm composting handbook. NRAES-54, Northeast Regional Agricultural Engineering Service, Ithaca, New York, p. 9.
- Soliva, M., F. Giro and S. Manzano. 1993. Nitrogen lost during composting at two facilities in Spain. *Compost Science and Utilization*, 1(4): 23-26.
- U.S. Department of Commerce, 1996. Bureau of the Census.
- Witter, E. and J. M. Lopez-Real. 1987. The potential of sewage sludge and composting in a nitrogen recycling strategy for agriculture. *Biological Agriculture and Horticulture*, 5:1-23.

**ATTACHMENT B**

## LEACHATE AND RUNOFF CHARACTERIZATION DURING CRAWFISH PROCESSING RESIDUALS AND RICE HULL COMPOSTING<sup>1</sup>

M. Y. Minkara, T. B Lawson<sup>2</sup>, and G. A. Breitenbeck

Louisiana State University Agricultural Center, Baton Rouge, LA

### ABSTRACT

Nutrient losses through leaching and rainfall runoff were evaluated over a 50-day period from a pilot-scale windrow composting project. Crawfish processing residuals and rice hulls were mixed in a 1:1 (w/w) ratio and used to construct three windrows on tarpaulin to capture leachate and runoff. Moisture for each windrow was supplied from (1) leachate and runoff, (2) tap water, and (3) natural rainfall water. Resulting nutrient analysis showed chemical oxygen demand from all windrow systems in the range of 300-4,500 mg/L. Ammonium-N, nitrate-N, and phosphorus losses totaled about 22 g  $\text{NH}_4\text{-N/kg N}$ , 2.2 g  $\text{NO}_3\text{-N/kg N}$ , and 62 mg P/kg solids of the initial compost, respectively, for the watered windrow over the 50-d period. Leachate and runoff addition to crawfish residuals and rice hulls composting windrow would save tap water need or relying on rainfall. However, this practice did not prove to increase the nutrients content of the final compost product. Leachate or runoff may be added only during the active period of composting.

**Keywords:** Fisheries by-products, crayfish, solid wastes, compost, nutrient loss, water quality

<sup>1</sup> Approved for publication by the Director of the Louisiana Agricultural Experiment Station as publication number 98- . Trade names are used solely to provide specific information. Mention of a trade name does not constitute a warranty by the Louisiana Agricultural Experiment Station of the LSU Agricultural Center of the product nor an endorsement to the exclusion of other products not mentioned.

<sup>2</sup> Author to whom correspondence should be addressed.

## INTRODUCTION

Management of leachate and rainfall runoff poses a challenging problem for composting operations, especially those composting fisheries by-products. Fisheries by-products tend to be putrescent, rich in nutrients, and have a high water content. Moisture contents in the range of 60-80% are very common (Brinton and Seekins, 1988). If not properly managed, leachate from fisheries by-products compost creates foul odors, attracts flies, or is otherwise aesthetically unacceptable (Frederick et al., 1989).

Windrow composting is a widely accepted practice for aerobic decomposition of many types of organic wastes. However, substantial amounts of nutrients may be lost in leachate and runoff from composting operations and threaten surface and groundwater quality (Ballesterio and Douglas, 1996; Kovacic et al., 1992). Characterization of leachate from compost operations is required by many permitting agencies and is necessary in determining site design parameters to minimize odors and other problems (Andree, 1991). Problems caused by leachate can trigger fines or closures by permitting agencies.

Effective management strategies for reducing leachate when composting fisheries by-products are not well established. Commonly, bulking agents with moderate to high moisture absorbency such as peat and sawdust are mixed with fisheries by-products to reduce leachate generation during composting (Brinton and Seekins, 1988). By reducing the amount of leachate and runoff, losses of inorganic nutrients and organic compounds can also be reduced (Ulén, 1993).

Rice hulls are highly effective as a bulking agent for composting crawfish processing residuals (Minkara et al., 1998). Rice hulls are light-weighted and easily turned. Because of their recalcitrance to microbial decomposition, they may be reused to dispose of several loads

of crawfish residuals. During their initial use, however, rice hulls resist wetting and are therefore more prone to produce leachate than other bulking agents.

Traditional leachate and runoff management techniques include storage and/or land application or discharge into a public sewer system. Recycling leachate by applying it to active compost piles for moisture control is an attractive, low-cost alternative (Spencer, 1991). This technique not only reduces the reliance on rainfall or the need for supplemental water sources but also may mitigate environmental impacts by reducing the quantity of leachate as well as its nutrient content and biological oxygen demand. The principal objective of this study was to compare the quality and characteristics of leachate/runoff generated by uncovered windrows consisted of crawfish residuals and rice hulls when (1) watered with leachate; (2) watered with tap water; or (3) unwatered except for rainfall.

## MATERIALS AND METHODS

### *Windrow Design*

Pilot-scale windrows (3 m long x 1.5 m wide x 1.5 m height) were constructed on impermeable polyethylene liners placed on a 5:1 slope that channeled leachate and runoff into a 300-L collector. Three windrows were constructed: (1) watered with leachate/runoff (L); (2) watered with tap water (W); and (3) unwatered except for rainfall (R).

The feedstock for each windrow consisted of 150 kg (wet weight) of crawfish residuals and 150 kg (wet weight) of rice hulls. The moisture content, bulk density, and organic carbon (C) and total nitrogen (N) concentrations of these materials were determined prior to use (Table 1). Similar volume of the stored leachate/runoff or tap water was applied by sprinkler to the corresponding windrow as required to maintain adequate moisture content. Tap water and leachate/runoff were added on days 2, 5, 8, 12, 19, and 30 to meet

moisture microbial demand and drying criteria. The windrows were turned manually 10 days and 30 days after construction to homogenize the materials. Passive aeration was provided by three perforated PVC pipes (10 cm diameter) positioned laterally across each windrow. Oxygen concentration measurements showed that passive aeration was adequate to maintain aerobic conditions throughout the composting period.

#### *Leachate/Runoff and Compost Sampling Procedure*

Leachate/runoff from the windrows was collected daily after each rainfall or watering event. Similar leachate/runoff volume was collected from each windrow. Triplicate leachate/runoff samples (~500 ml) were analyzed for pH, chemical oxygen demand (COD), nitrate ( $\text{NO}_3$ ), ammonium ( $\text{NH}_4$ ), and primary elements (Mg, Mn, Na, K, P, and S). Volume remained after sampling from the L collector was stored in a 900-L reservoir and used later for watering. Volume remained from the W and R collectors was discarded after sampling. Three compost samples (~50 g each) were collected twice weekly from each windrow middle section at three locations along the windrow length. Compost samples were analyzed for moisture content, volatile solids, organic C, total N,  $\text{NO}_3\text{-N}$ ,  $\text{NH}_4\text{-N}$ , and primary elements. Data reported for leachate/runoff and compost samples are the means of three samples.

#### *Measurements and Analytical Methods*

Compost temperature was measured with copper-constantan thermocouples at four equally-spaced locations along the windrow length and connected to a datalogger (model CR7, Campbell Scientific, Logan, UT). Percent oxygen in the compost airspace was measured three times weekly using a model OT-21 oxygen meter and probe (Demista Instruments, Wheeling, IL).

Compost moisture content was determined twice weekly by the gravimetric method (APHA et al., 1992). After drying, samples were ground to 150-mesh size, thoroughly mixed and stored in air-tight containers for further analysis. Approximately 5-g subsamples were combusted at 550°C to determine volatile solids content. About 20-mg subsamples were used for organic C and total N determination using a Heraeus model CHN-O Rapid Analyzer. Nitrate-N and ammonium-N concentrations in compost and leachate/runoff were determined using a Wescan model 360 Analyzer (Wescan Instrument Inc., Deerfield, IL). Leachate/runoff pH was measured in-situ with a Digi-Sense 5939-10 digital pH meter (Cole-Parmer Instrument Co., Niles, IL). Leachate/runoff COD was determined by the titrimetric method (APHA et al., 1992) using accu-TEST™ vials (Bioscience, Inc., Bethlehem, PA). Approximately 500 mg of ground compost were digested with 16 N nitric acid for elemental analysis. Elemental analysis of compost extract and leachate/runoff were determined by the Inductively Coupled Plasma (ICP) method (APHA et al., 1992).

## RESULTS AND DISCUSSION

### *Compost Characteristics*

Moisture content remained in the desirable range (35-60%) during most of the composting process for the L and W windrows but not for the R windrow (Fig. 1). Although the L and W windrows were frequently watered during the first two weeks, the maximum moisture content achieved during that period was only 42%. After turning on day 17, moisture content consistently remained between 40-60%. Degradation of crawfish residuals apparently facilitated moisture retention by rice hulls. Although the moisture content for the R windrow was relatively low, this windrow maintained similar temperature profile to the others during most of the 50-d composting study (Fig. 2). This is probably due to a greater



heat capacity of the relatively drier R windrow. By the third day, all windrows had reached their highest temperature of 60°C. Shortly thereafter, temperature dropped to about 45°C. Temperature then declined gradually to near ambient (30°C) at about day 40. This suggests that the self-heating phenomena had ceased and the available substrate had reduced.

During composting, the volatile solids content tends to decrease due to microbial degradation of organic matter and production of carbon dioxide. For all windrows, the period between day 10 and day 20 and the period between day 30 and day 37 observed the greatest drop in volatile solids (Fig. 3). This decrease in volatile solids had followed the mixing of the composting materials. Because of the heterogeneous nature of the feedstock, variation in volatile solids within the same windrow, was greater during the first half of the experiment where the crawfish residuals became mostly degraded. By the end of the composting experiment, the R windrow had a significantly higher volatile solids content (63.1%) than either the L (60.9%) or W (60.2%) windrow ( $P=0.01$ ,  $\alpha=0.05$ ). The addition of leachate/runoff on day 30 may have led to these higher values in volatile solids in the L windrow than the W windrow, after 35 d of composting. This is due to the unstable organic matter contained in the leachate and runoff. Therefore, it is recommended that leachate and runoff reuse for moisture control be adopted only during the early period of high decomposition for batch composting. In this manner, the leachate/runoff can be metabolized by the composting organisms. The leachate/runoff may not contain enough energy substrate for microbial communities to heat up the windrow once the main substrate (i.e. crawfish residual) is consumed during the late stage of the composting process.

Organic C concentration of the composted material was reduced from an average initial value of about 394 g/kg to final values of about 351, 348, and 362 g/kg for L, W, and

R, respectively (Table 2). The R windrow had the smallest final C concentration simply because crawfish residuals were not completely degraded. Final C concentration for L was slightly higher than that of W since L received organic C contained in the leachate/runoff added to the windrow on day 30.

Total N concentration was reduced from an initial value of 15.8 g N/kg to 9.2, 8.9, and 11.2 g N/kg for L, W, and R windrows, respectively. Final total N was the highest for the R windrow since crawfish residuals were not completely degraded. For the same reason, the R windrow had very high final  $\text{NH}_4$  concentration (330.4 mg  $\text{NH}_4\text{-N}$  /kg) and low final  $\text{NO}_3$  concentration (47.4 mg  $\text{NO}_3\text{-N}$ /kg) compared to the L or W windrows at the end of the 50-d composting period. No significance difference was observed in the final total N,  $\text{NH}_4$  and  $\text{NO}_3$  concentrations between L and W windrows (Table 2). It appears that the addition of leachate/runoff to a composting mixture of rice hulls and crawfish residuals does not result in an increase in final compost total N,  $\text{NH}_4$ , or  $\text{NO}_3$  concentrations in comparison to the addition of tap water.

During composting, organic materials undergo mineralization and transformation into more stable product by the action of microorganisms. Organic- as well as inorganic-compounds are consumed by microorganisms. Inorganics are usually considered a minor source of nutrients for composting microorganisms. During organic material degradation, inorganics are released from their complex form and could be subject to losses (Rymshaw et al., 1992). Because of the reduction in the mass of organic compounds during composting, element concentration per dry weight may increase or remain the same if no actual losses by leachate and runoff occur. In this experiment, compost Mg, Mn, Na, K, P, and S concentrations on dry weight basis did not significantly change for neither L, W, or R

windrows from their initial concentrations (Table 3). Since Ca is a major constituent of ash, the increase in ash (i.e. decrease in volatile solids) led to an increase in Ca concentration as well. Therefore, the addition of leachate/runoff to an active compost pile does not suggest an increase in the nutrient concentration of the compost product. However, this practice can mitigate the impact of composting operations from excessive nutrients, minerals, organics, and heavy metals loading into surface and ground waters.

#### *Leachate/runoff Characteristics*

For all windrows, leachate/runoff had a rapid pH increase from near neutral pH (6.8) on the first day to alkaline pH (9.2) on day 5 (Fig. 4). This initial rapid pH increase is probably due to ammonification and its role as a proton sink (Miller, 1992). The pH then fluctuated between 8 and 9 for the next 10 days. For the rest of the period, pH varied between 7 and 8, however, the R windrow maintained higher pH probably due to its continuous generation of  $\text{NH}_3$ . At the end of 50-d composting period, pH was about 7.2 for L and W windrows, and 7.5 for R windrow.

In general, the amount of rainfall or water added to a windrow will have a direct effect on the amount of nutrient losses. Nutrient losses are attributed also to the nutrient concentration in the compost mixture and its availability to leaching. Daily leachate/runoff volume and nutrient concentration, following a rainfall or watering event, were used to determine nutrient losses from the windrow. Nutrient losses are presented here only for the W windrow depicting the common practice of windrow watering.

Ammonium losses in leachate/runoff were elevated, especially during the first 25 days where degradation and mineralization rates are at maximum (Fig. 5). Ammonium loss totaled about 22 g  $\text{NH}_4\text{-N/kg N}$  (347 mg  $\text{NH}_4\text{-N/kg solids}$ ) of initial compost from

the W windrow over the 50-d period. During the highly active period, the readily available substrate and the favorably composting conditions initiated  $\text{NH}_4$  generation resulting from the rapid ammonification of organic-nitrogenous compounds. Ammonium losses were reduced from 4.4 g  $\text{NH}_4\text{-N/kg N}$  on day 15 to 1.3 and 0.1 g  $\text{NH}_4\text{-N/kg N}$  on days 26 and 42, respectively, where leachate/runoff volumes collected on these three days were comparable (around 80 L). For the W windrow, ammonium concentration peaked at 190.6 mg  $\text{NH}_4\text{-N/L}$  on day 14 when leachate/runoff volume was 18.9 L, and it reached a minimum value (0.43 mg  $\text{NH}_4\text{-N/L}$ ) on day 50 although leachate/runoff volume was only 0.2 L. A typical  $\text{NH}_4$  concentration range in municipal effluent is between 12 and 50 mg/L (Rymshaw et al., 1992).

Nitrate losses were fairly distributed for the W windrow over the 50-d period (Fig. 6). Nitrate is highly soluble and is easily leached by water from the compost windrow. Nitrate total losses amounted to 2.23 g  $\text{NO}_3\text{-N/kg N}$  (35.8 mg  $\text{NO}_3\text{-N/kg solids}$ ) of initial compost for the W windrow. Nitrate losses were lower than ammonium losses presumably due to the lower rate of nitrification compared to the rate of ammonification. Nitrate losses in leachate/runoff peaked at day 24, resulting from the 143.8 L leachate/runoff volume collected from rainfall and amounted to 0.46 g  $\text{NO}_3\text{-N/kg N}$ . Nitrate maximum concentrations of 38.8 and 23.5 mg  $\text{NO}_3\text{-N/L}$  for the W and R windrows, respectively, were reached on day 36, when volume collected was 11.3 L. Ballesteros and Douglas (1996) determined that horse-bedding compost lost 230 g total N/kg of compost initially present over a 60-d study period, which is much higher than the combined amount of  $\text{NH}_4$  and  $\text{NO}_3$  lost in this experiment. Ulén (1993) found that an

average of 48.8 g total N/kg N initially present were leached over a seven-month winter experiment from straw and manure compost.

Phosphorous is the limiting nutrient causing eutrofication in surface water from land runoff; therefore, it is important to document phosphorous losses from composting operations. Phosphorus losses from the W windrow were peaked on day 24 and they amounted to 14.1 mg P/mg solids (Fig. 7). Most of the soluble-P was leached during the first 25 days. Phosphorus losses were reduced from 8.5 mg P/mg solids of initial compost on day 15 to 4.8 and 2.3 g mg P/mg solids on days 26 and 42, respectively, where volumes collected on these three days were comparable (around 80 L). Over the 50-d period, total soluble-P losses were 59.5 mg P/kg solids. Maximum P concentration of 46.6 mg P/L was reached on day 19 for the W windrow, where total volume collected was 3.8 L. Typical phosphate concentration range in municipal effluent is between 6-20 mg/L (Rymshaw et al., 1992). Ulén (1993) observed a mean loss of 24 g P/kg P in winter compost leachate and a typical total-P concentration of 50 mg/L in runoff from straw and manure compost.

Organic C is mainly released during the early stages of composting processes when the organic substrate is highly subject to degradation by microorganisms. Chemical oxygen demand (COD) in leachate/runoff was measured to estimate organic C losses. In this experiment, COD loading was mainly during the first 25 d for the W windrow (Fig. 8). The COD losses were reduced from 1.6 to 1.3 g COD/kg C of initial compost from day 24 to day 48, in which the volume collected was doubled on the latter day. This shows that COD concentration was reduced over a half from day 24 to day 48. Maximum COD concentrations of 4,587 and 3,980 mg/L were reached on day 19 and day

7, for the W and R windrows, respectively. Total COD loading over the 50-d period was 11.2 g COD/kg C (4.4 g COD/kg solids) from the W windrow. The COD concentrations observed here are comparable to COD values from runoff of an open dairy lot, which range from 2,300 to 5,000 mg/L (Sweeten and Wolfe, 1990).

### CONCLUSIONS

During composting crawfish residuals and rice hulls, excessive amounts of nutrient were released through leaching and runoff. Movement of these nutrients could have a detrimental effect on surface and ground waters quality if not properly managed. Organic C and  $\text{NH}_4$  are mainly leached in the early phase of the composting process during high decomposition rate of organic substrate. The release of nitrate and other elements in leachate and runoff results from the mineralization process of organic compounds. Attenuation of nutrient losses in leachate and runoff occurs toward the end of the composting process.

The use of leachate/runoff on active compost would save fresh water need for compost piles or relying on rainfall while reducing the leachate and runoff amounts that may undergo conventional treatment methods. The addition of leachate/runoff needs to be adopted only during the high microbial activity period to allow for the assimilation of its organic content.

Compost nutrient retention from the application of leachate/runoff to active compost consisting of different feedstock merits further investigation. Further research is needed to characterize the leachate and runoff in various composting environments and weather conditions. Characterizing the leachate and runoff can provide valuable information for better design and operation of compost facilities.

## ACKNOWLEDGMENTS

This research was supported in part by a grant from the Louisiana Department of Environmental Quality. The laboratory assistance of Mr. David Schellinger, Louisiana State University Agronomy Department, was greatly appreciated. Thanks to Ms. Louise Braud, Louisiana State University Biological and Agricultural Engineering Department, for her help in collecting and analyzing research samples.

## REFERENCES

- American Public Health Association (APHA), American Water Works Association, and Water Pollution Control Federation. 1992. *Standard Methods for the Examination of Water and Wastewater*. 18th edition. APHA, Washington, DC.
- Andree, S. 1991. Implementing fisheries by-products composting applications: The next step. *Proceedings of the 1991 Fisheries By-Products Composting Conference*. Madison, WI. pp. 181-187.
- Ballesterio, T. P. and E. M. Douglas. 1996. Comparison between the nitrogen fluxes from composting farm wastes and composting yard wastes. *Transactions of the ASAE*. 39(5): 1709-1715.
- Brinton, W. F. and M. D. Seekins. 1988. Composting Fish By-Products: A Feasibility Study. Time & Tide RC & D, Waldodoro, ME.
- Frederick, L, R. Harris, L. Peterson, and S. Kehrmeyer. 1989. The Compost Solution to Dockside Fish Wastes. WIS-SG-89-434. University of Wisconsin Sea Grant Advisory Services, Madison, WI.
- Kovacic, D. A., R. A. Cahill, and T. J. Bicki. 1992. Compost: Brown gold or toxic trouble? *Environmental Science and Technology*, 26(1):38-41.
- Minkara, M. Y., T. B. Lawson, G. A. Breitenbeck, and B. J. Cochran. 1998. Co-composting of crawfish and agricultural processing by-products. *Compost Science and Utilization*, 6(1):67-74.
- Spencer, R. 1991. Leachate management at a composting facility. *Biocycle*, 32(10):38-39.
- Sweeten, J.M. and M. L. Wolfe. 1990. Runoff and wastewater management systems for open lot dairies. *Proceedings of the six International Symposium on Agricultural and Food Processing Wastes*, Chicago, IL. pp. 361-375.

Miller, F. C. 1992. Composting as a process based on the control of ecologically selective factors. In: *Soil Microbial Ecology* by F. B. Metting, Jr. editor., Marcel Dekker, NY. pp. 514-544.

Rymshaw, E., M. F. Walter, and T. L. Richard. 1992. Agricultural composting: Environmental monitoring and management practices. Department of Agricultural Engineering, Cornell University, Ithaca, NY.

Ulén, B. 1993. Losses of nutrients through leaching and surface runoff from manure-containing composts. *Biological Agriculture and Horticulture*, 10:29-37.



## CAPTIONS FOR FIGURES

Figure 1. Moisture content of compost during the 50-d study period. Arrows represent the times when the leachate/runoff or tap water were added to moisten the L and W windrows. L = watered with leachate; W = watered with tap water; R = unwatered except for rainfall.

Figure 2. Average compost and ambient air temperatures. Arrows represent the times when the windrows were turned. L = watered with leachate; W = watered with tap water; R = unwatered except for rainfall.

Figure 3. Change of volatile solids content of compost during the 50-d study period. Arrows represent the times when the leachate/runoff or tap water were added to moisten the L and W windrows. Error bars are the standard deviations. L = watered with leachate; W = watered with tap water; R = unwatered except for rainfall.

Figure 4. Leachate/runoff pH from the L, W, and R windrows during the 50-d study period. L = watered with leachate; W = watered with tap water; R = unwatered except for rainfall.

Figure 5. Ammonium losses in leachate/runoff from the windrow watered by tap water expressed in g per kg total N of the initial compost dry mass.

Figure 6. Nitrate losses in leachate/runoff from the windrow watered by tap water expressed in g per kg total N of the initial compost dry mass.

Figure 7. Phosphorus losses in leachate/runoff from the windrow watered by tap water expressed in g per kg of the initial compost dry mass.

Figure 8. Organic carbon losses in leachate/runoff from the windrow watered by tap water expressed as chemical oxygen demand (COD) in g per kg C of the initial compost dry mass.

Table 1. Characteristics of rice hulls and crawfish residuals.

Material	Moisture Content*	Bulk Density*	Organic C	Total N	C:N
	%	(kg/m <sup>3</sup> )	(g/kg solids)		
Rice Hulls	9.5	104.4	372.0	4.8	76.9
Crawfish	66.2	466.4	317.3	50.3	6.3

\* Moist basis

Table 2. Carbon, nitrogen, ammonium and nitrate concentrations, and C:N ratios in initial and final compost from three windrows under three water regimes<sup>^</sup>.

Property	Units	Initial	Final			LSD <sub>0.05</sub> *
			L	W	R	
Organic C	g/kg solids	394.2	351.1	348.4	362.5	1.5
Total N	g/kg solids	15.8	9.2	8.9	11.2	0.4
C:N	-	24.9	38.2	39.1	32.4	11
NH <sub>4</sub> -N	mg/kg solids	280.6	43.4	48.4	330.4	54
NO <sub>3</sub> -N	mg/kg solids	34.2	156.7	156.8	47.4	23

<sup>^</sup> L = Watered with leachate; W = Watered with tap water; R = Unwatered except for rainfall;

Values are means of triplicate samples

\* Least significance difference

Table 3. Initial and final concentrations of principal nutrients in g/kg solids for the three windrows<sup>a</sup>.

Element	Initial	Final			LSD <sub>0.05</sub> <sup>*</sup>
		L	W	R	
Mg	0.78	0.95	0.94	0.97	0.22
Mn	0.24	0.25	0.28	0.24	0.04
Na	1.29	1.44	1.45	1.48	0.33
Ca	32.1	42.1	44.3	47.4	4.62
K	2.98	3.05	2.71	2.94	0.19
P	2.19	2.43	2.50	2.66	0.80
S	1.48	1.35	1.35	1.44	0.29

<sup>a</sup> L = Watered with leachate; W = Watered with tap water; R = Unwatered except for rainfall;

Values are means of triplicate samples

\* Least significance difference

Fig. 2

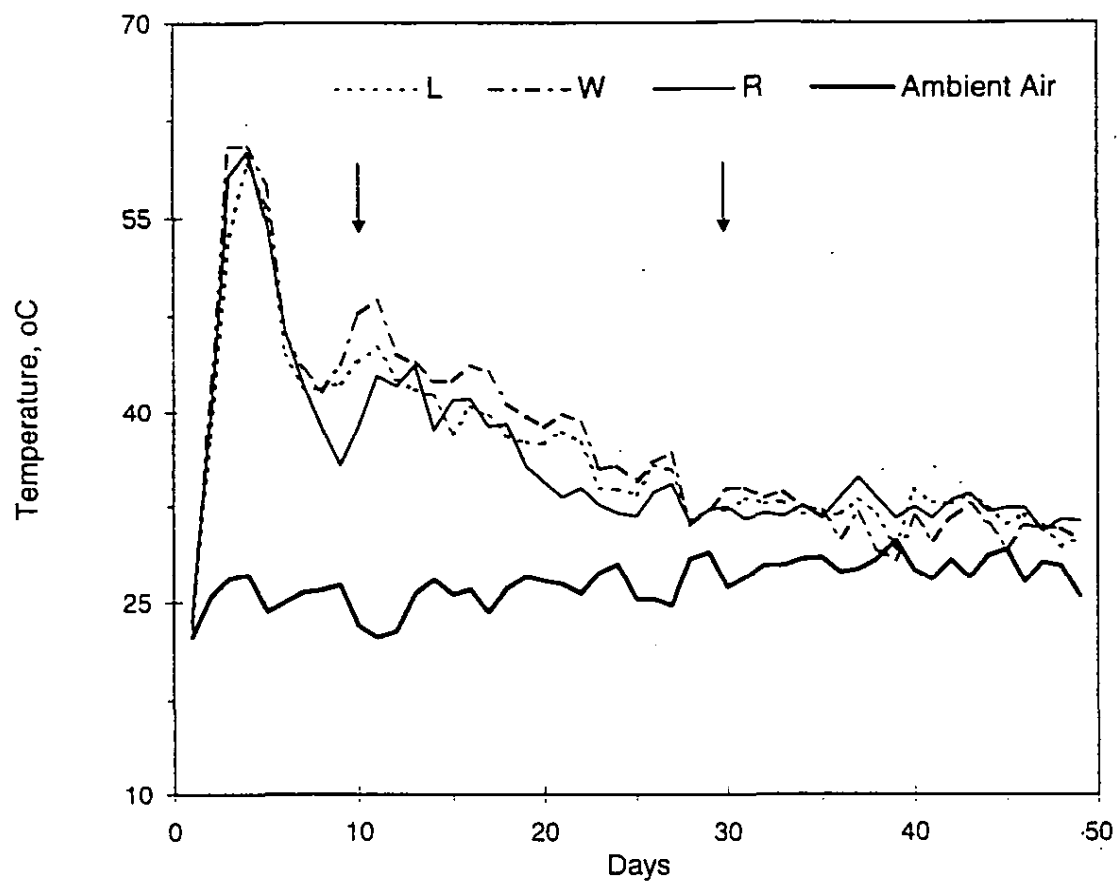


Fig. 3

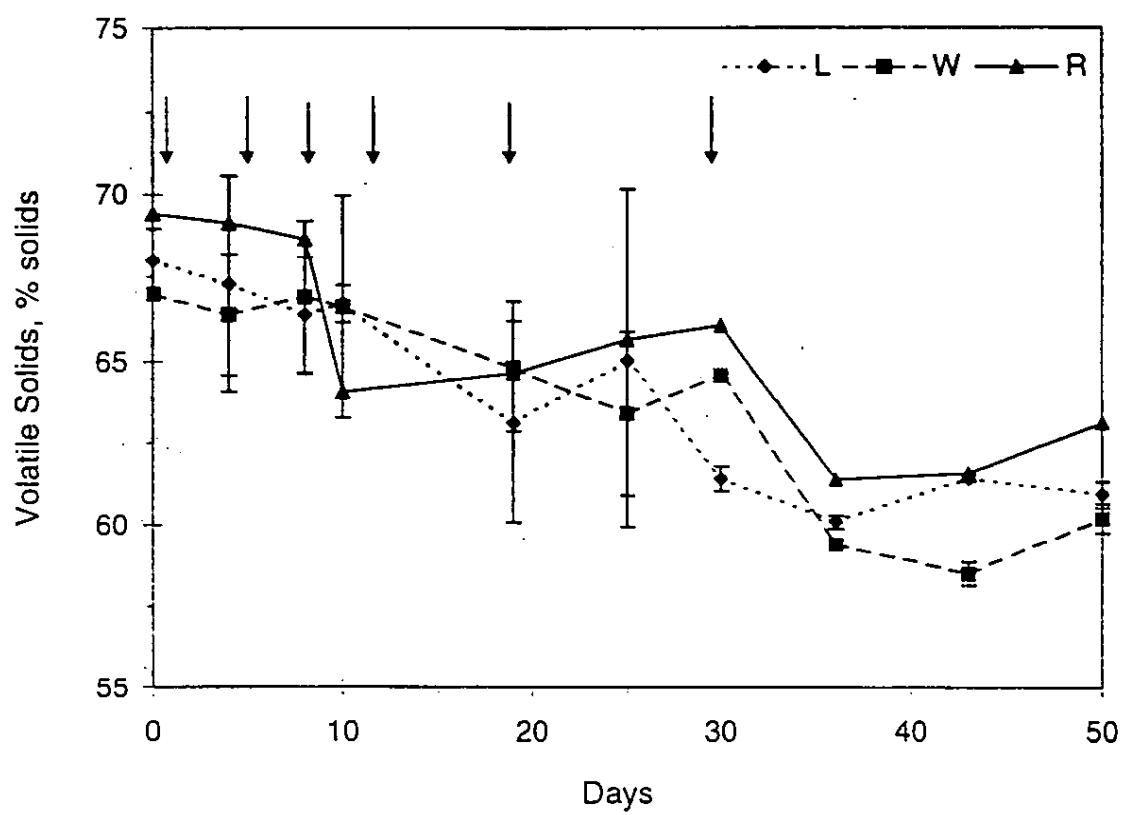


Fig. 4

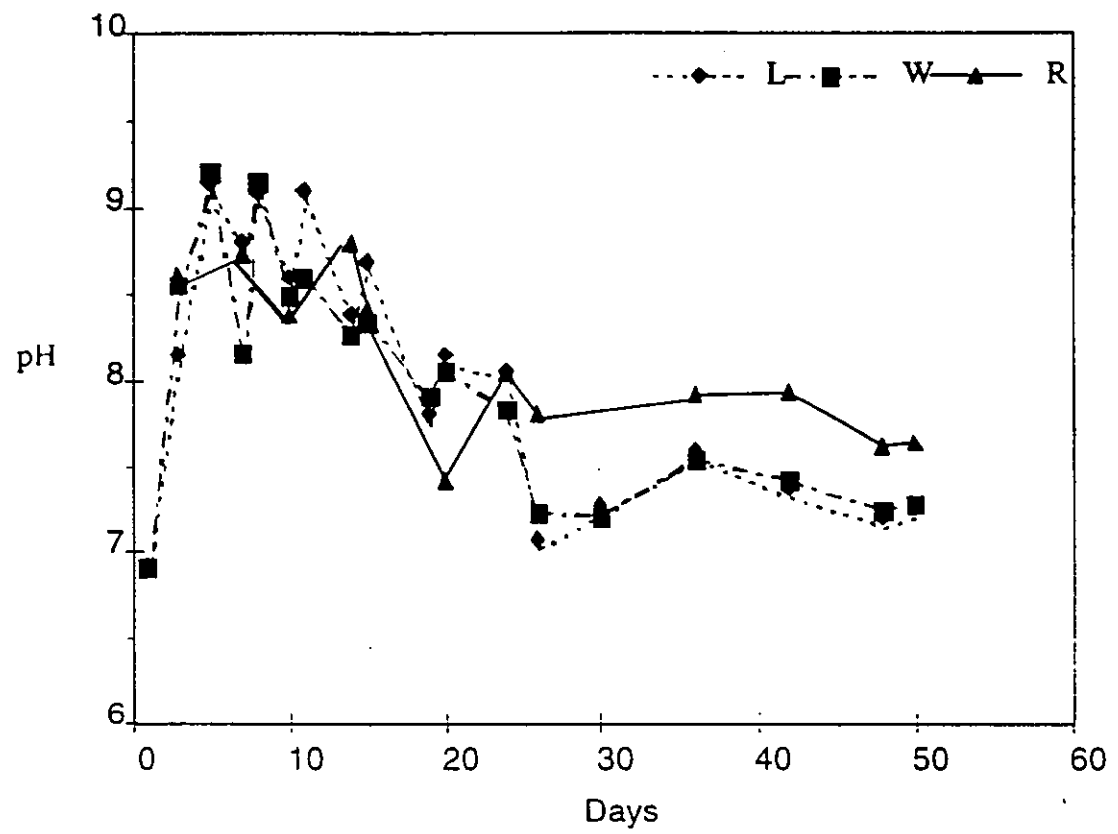


Fig. 5

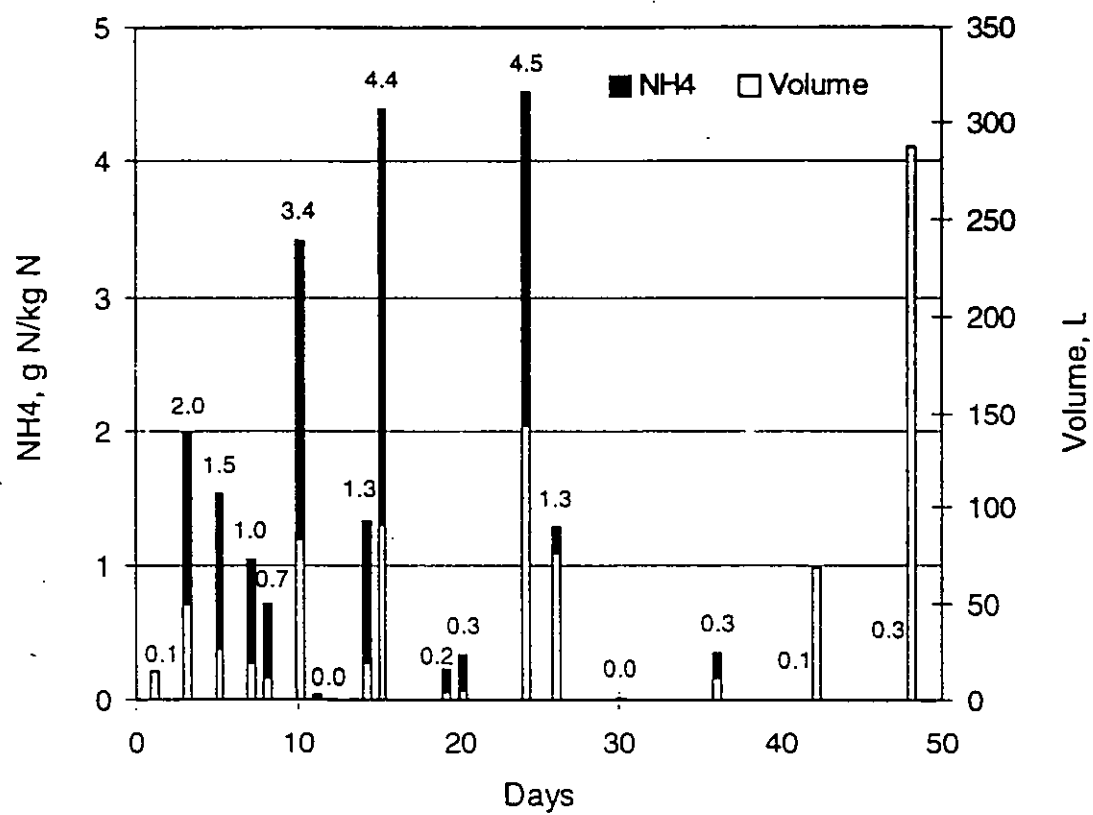




Fig. 6

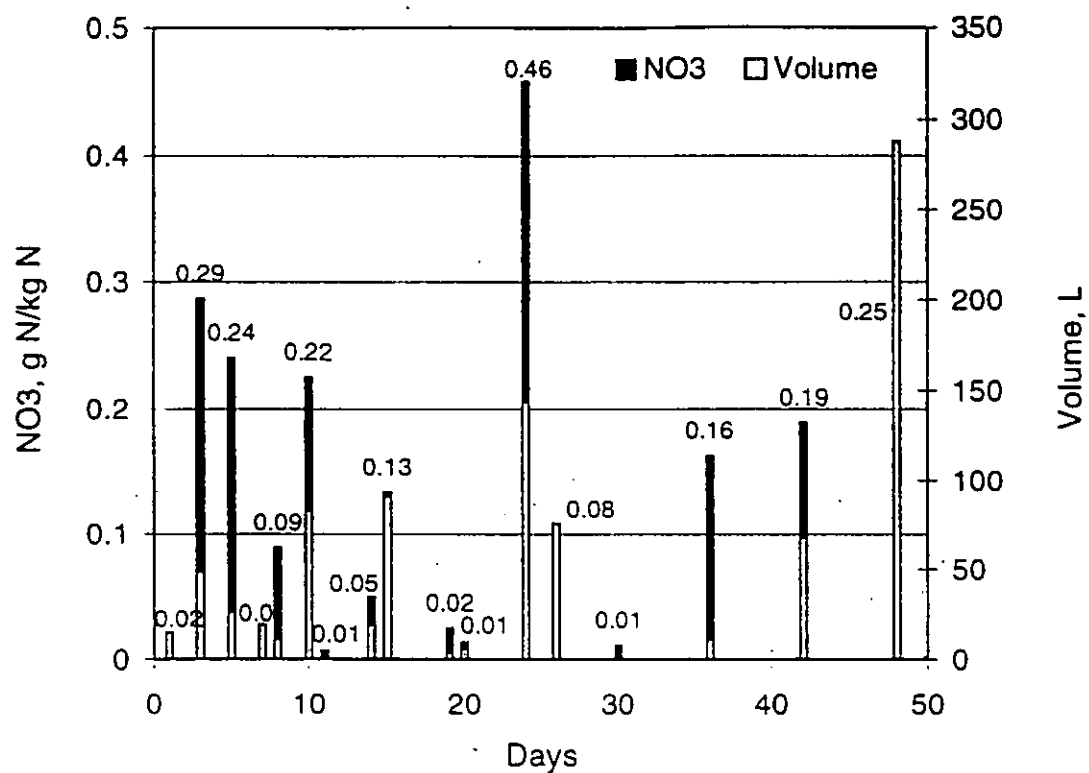


Fig. 7

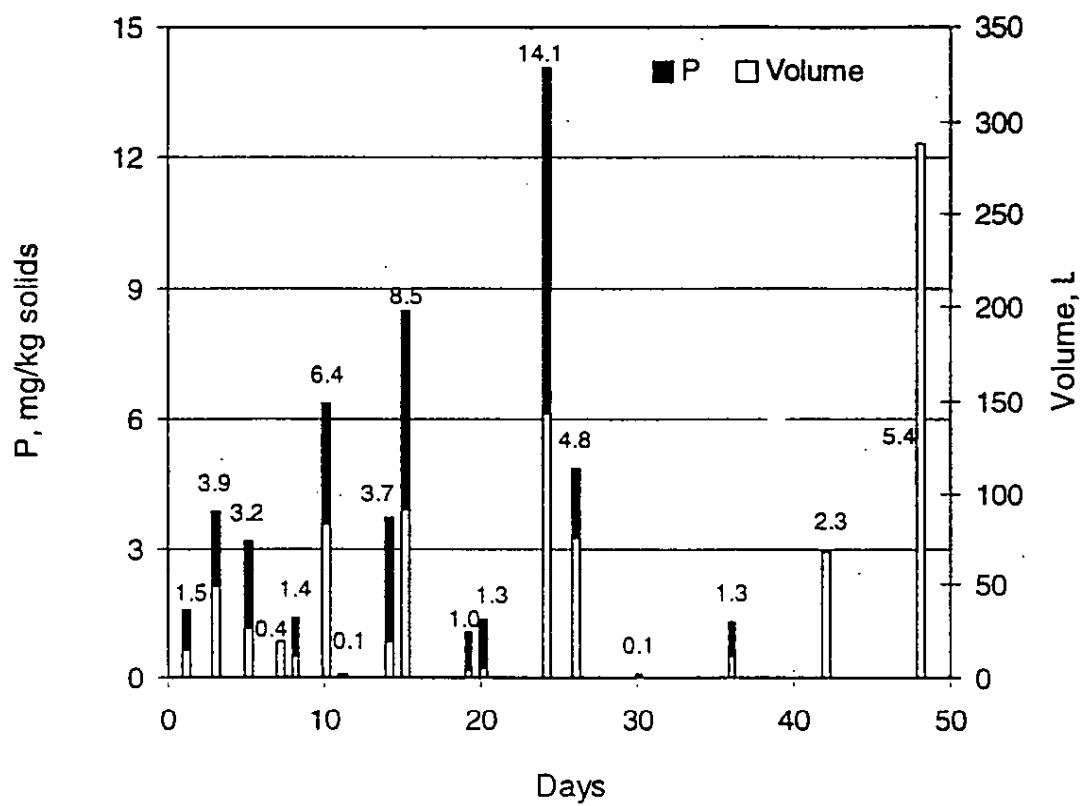
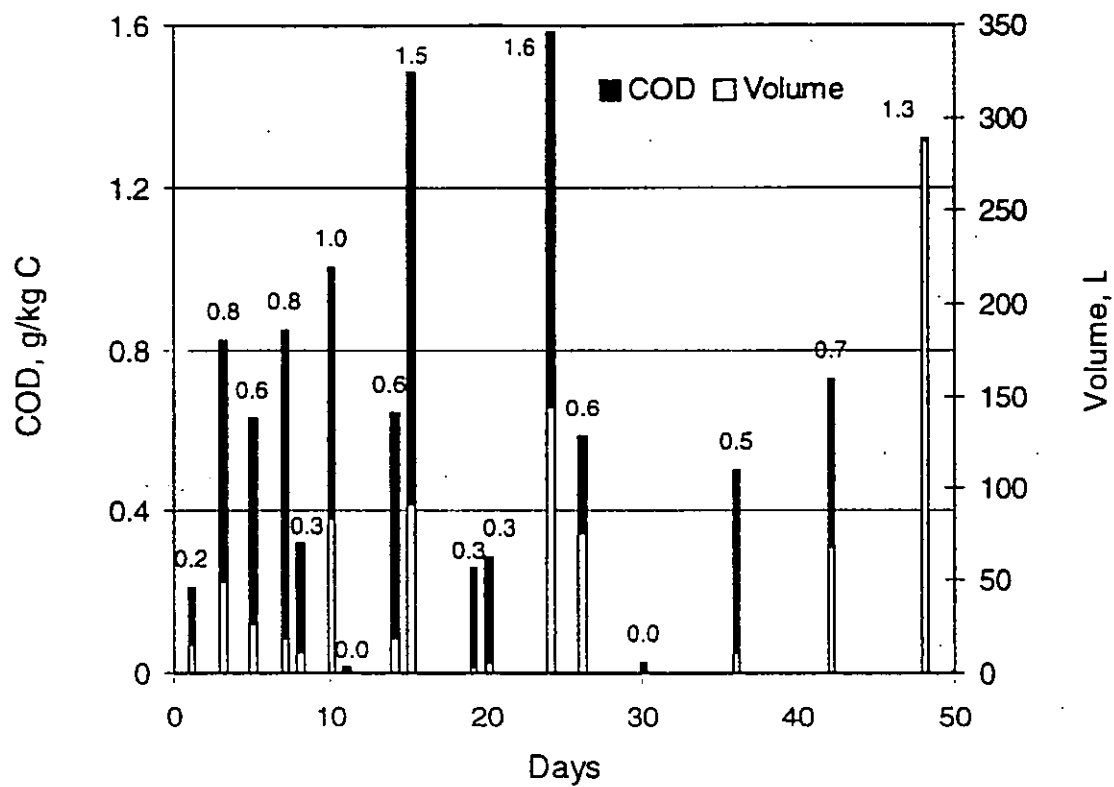


Fig. 8



# School shows how to turn trash into treasure

It's like turning a sow's ear into a silk purse. Participants in the LSU Agricultural Center's 8th semiannual compost facility operation training schooling learned to transform garbage into something valued by society.

"By using compost on some drought-prone cotton fields in Northeast Louisiana, we nearly doubled yields," said Extension agent Station agent Gary Breitenbeck, one of the teachers at the school, while cutting air to sample from LSU Ag Center research of the beneficial effects of compost.

The 22 students in the week-long school, which ended May 15, came from seven states and one other country — Japan — and represented municipalities, prisons, the U.S. Air Force and small businesses.

"We get students from all over," said Extension Service environmental education specialist Bill Carney, who is the coordinator of the Ag Center course that began in 1994. "We had people come from Israel a couple of years ago."

Though Carney says he does not advertise the course, news spreads by word of mouth and the Internet, so there never is a room for all who apply because of a limit of 20-25 students.

The course includes intensive training in the chemistry and biology of making compost. Students learn not only in the classroom but also by donning hard hats and safety goggles and digging into compost piles at the LSU Ag Center's composting facility.

That composting facility is a

and cotton by-products. After curing, the finished compost is coarse, relatively odor-free and looks like potting soil.

"The school is definitely hands-on," Breitenbeck said. Under a tent at the facility, he sets up a miniature chemistry lab and teaches the students to use various instruments to measure carbons, nitrogen, oxygen, moisture content and other important compost features.

He divides the group into teams that must compete to see who can build the best compost pile and correctly find different characteristics in the compost piles already there. For example, they need to find the pile with three times more carbon dioxide than oxygen and the pile with the highest acidic content.

"This helps them learn and makes the school worthwhile," Breitenbeck said.

Rhonda Sherman-Huntton, an extension specialist from North Carolina State University in Raleigh who was one of the students, agrees. She helps teach a similar course there — although she says it is not as intensive.

"I came here to learn because of the reputation of the school," she said. "This school has more field work than others."

The city of Lafayette has sent representatives to six of the schools, which are now held both spring and fall.

"That city is very progressive with its waste management program," Carney said. "We've trained everybody on the staff. Their compost facility has saved the city about \$2.5 million so far."

Military units and prisons



Participants in the LSU Agricultural Center's 8th semiannual compost facility operation training school learned, among other things, to take samples from compost piles to check for chemical composition. The students came from across the state and the country. Shown here are, from left, Dean Domingues from the city of Lafayette; Trace Breland, Gulfport, Miss., naval base; Steven Yu, Department of Corrections, Tallahassee, Fla.; Dalton Darden, Global Environment, Columbia; Keith Kember, Air Fuels, Napoleonville; and Gary Breitenbeck, an LSU Ag Center agronomist who was one of the teachers at the school.

with their waste."

Employees at an Air Force base in Alabama reported back to Carney that they had won that state's best compost facility award for 1995. They had attended the school the year before.

Many of the participants are entrepreneurs looking at ways to make money. Compost is valuable for commercial agriculture because, when worked into soil, it adds nutrients and structure that allow water and air to help plants grow. This is especially important in states like Louisiana where the soil is not very good.

"We need more people in the business who can match the

Carney said of the whole field of waste management and making compost. "There aren't enough landfills. And the landfills we have are closing."

In Louisiana, for example, the number of landfills went from 800 in 1980 to 30 this year. The state Department of Environmental Quality said that number will be reduced to 11 by the year 2000.

The LSU Ag Center's compost facility includes demonstration versions of three of the main pieces of equipment needed at a composting facility — tub grinder, trommel screen and windrow turner.

Materials rotate in a screened drum so pieces that are too large can be filtered out. The windrow turner is a device that mixes the compost once it has been put into elongated piles about 5 feet tall called "windrows." Periodic turning helps the waste product "cure" into compost.

"This is the best research facility in the country," Breitenbeck said. "But we want to get better."

Breitenbeck and Carney are working to get funding to expand the capabilities of the facility to take in and compost municipal biosolids and hazard-

**ATTACHMENT E**

## Experiment Dispels Fishy Smell; Rice Hull Compost Solves Problem at Grand Isle

To the thousands of people who venture off the Louisiana coast every year to the resort island of Grand Isle, the fish aroma that permeates the air may be sweet – up to a point.

That's where an LSU Agricultural Center experiment comes in.

Dr. Tom Lawson, a biological engineer, and Dr. Gary Breitenbeck, a soil scientist, have developed a quick, easy, inexpensive and even stylish way to get rid of unwanted fish parts and their offensive odor. They do this by composting, and the resulting odor-free compost can be used to improve the quality of the island's soil.

Using 5-foot wide sections of 4-foot high wood fence, the scientists from the Louisiana Agricultural Experiment Station, the Ag Center's research branch, have designed a three-compartment fish composting station that easily can be situated near areas where people clean fish.

The two Ag Center scientists use rice hulls, an odorless, reusable product left over from milling rice, to speed fish decomposition and dispel the odor.

"The rice mills are looking for ways to get rid of this material,"

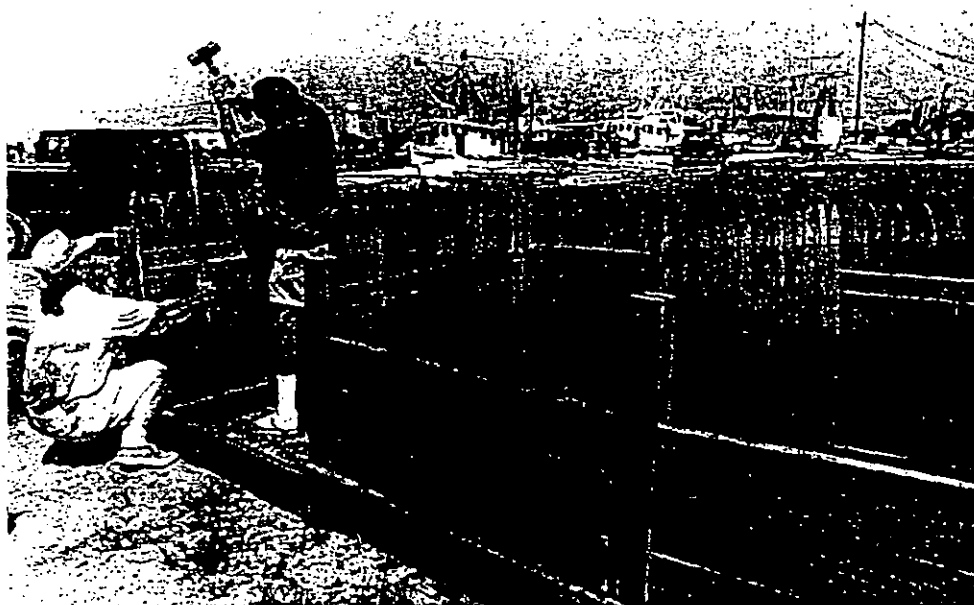
Breitenbeck said. "They'll charge \$5 a ton plus shipping."

Since rice hulls contain silica – like sand – they decompose very slowly, Breitenbeck said. However, when mixed with nitrogen materials, like fish waste, rice hulls help decompose them and can be used again.

Here's how their fish waste composter works: They fill one compartment with rice hulls and leave one compartment empty. The bottom of the third compartment is covered with about 8 inches of the hulls. Then people can dump in fish waste to a level about 6-8 inches deep. And they add another layer of rice hulls, about 3 inches deep.

When the compartment is filled with layers and capped with a 6- to 8-inch layer of rice hulls, it is allowed to compost for several days. The material is then turned into the empty bin, and the process starts over again.

Lawson, Breitenbeck and research associate David Schellinger built two fish waste composters at Grand Isle in June. Building one station, with materials that had been cut prior to the project, took only about an hour. The cost in materials is about \$300 for each station, Lawson said. ■



### Dispelling 'Fishy' Smell

Dr. Tom Lawson, a biological engineer with the LSU Ag Center, standing, has designed a fish composting station, which is relatively easy to construct, as a way to get rid of unwanted fish parts and their offensive odor. Research associate David Schellinger is helping him construct this one at Grand Isle, and they say the secret to dispelling the smell is to layer the unwanted fish parts with rice hulls — a product left over from rice milling —

**ATTACHMENT F**

# **FISH WASTE COMPOSTING: A HOW-TO MANUAL**

BY

THOMAS B. LAWSON  
DEPARTMENT OF BIOLOGICAL & AGRICULTURAL  
ENGINEERING

GARY BREITENBECK  
AGRONOMY DEPARTMENT

AND

DAVID SCHELLINGER  
AGRONOMY DEPARTMENT

Louisiana State University Agricultural Center  
Louisiana Agricultural Experiment Station  
Baton Rouge, LA 70803

1998



## Fish Waste Composting: A How-To Manual

**What is Compost?** Many people associate the word compost with manure. However, compost is not always manure. Compost is the end-product of the natural degradation of organic matter by microorganisms. The result is a dark, humus-like substance which resembles soil.

All organic materials will decompose over time and, given the right conditions, will form compost. Examples of materials which are routinely composted are: leaves, grass clippings, garden refuse, garbage, animal bedding, cotton gin trash, silage, sewage sludge, waste cardboard and paper, poultry mortalities and food processing residuals. Fish cleaning wastes, such as frames and offal from cleaning stations, are highly putrescent and decompose very rapidly. These types of wastes are very amenable to disposal by composting. Controlled composting speeds the natural breakdown of organic wastes by microbes such as bacteria and fungi.

**How is Compost Made?** Many organic materials which are composted are high in nitrogen. The waste from fish cleaning stations is a prime example. This material is not composted by heaping into piles and allowed to decompose. This will result in a smelly mess, and your neighbors will be very unhappy with you. Rather, highly putrescent organic materials are mixed with other materials, called bulking agents, which are low in nitrogen and high in carbon. Examples are pine straw, tree bark, hay, rice hulls, bagasse, shredded paper, sawdust, and the like.

A compost pile is constructed by mixing the organic material to be composted with the bulking agent. They can be mixed together before placing in the compost pile or they can be layered as they are added to the compost pile. Usually 2-3 times as much bulking agent is added as organic material. Depending on the type of materials used, this can be done by weight or by volume.

**Why Do I Need A Bulking Agent?** Compost needs several ingredients in order to decompose rapidly. Nitrogen and carbon need to be supplied as nutrients to the microbes so they can grow and do their work. If the carbon to nitrogen ratio (C:N) is too far out of balance, decomposition will not proceed properly. A C:N ratio in the range 20 - 40 is recommended. This is why bulking agents are mixed with materials high in nitrogen, to bring the C:N ratio into balance.

**Why Do I Need To Turn The Pile And Add Water?** In addition to nutrients, microbes need water and oxygen. After the materials are added to the pile, they are allowed to sit for several weeks or months to decompose and form compost. During the decomposition period, water must periodically be added to keep the pile moist. Water can be added with a garden hose during long dry periods. Compost should never get "soggy", or odors will develop. Also, the pile must be turned every 10-14 days to aerate the mass and keep it from becoming odorous. This can be accomplished by hand with a pitchfork or shovel, or it can be done mechanically with a compost turner or front end loader. In large commercial or municipal compost facilities large tractor-drawn compost turners are used to aerate the piles. During or after turning is usually the time to add water to the pile.

**How Do I Contain The Pile?** In commercial or municipal composting facilities, materials are usually placed on the ground in long narrow piles, called windrows. In some facilities composting is done on large concrete pads. The piles can be mechanically aerated or turned with windrow turners. Where smaller amounts of materials are composted, it is often more practical to contain the material in a bin or some other type of enclosure rather than to stack it in a loose heap. Many types of compost bins are commercially available, ranging from small plastic backyard bins holding about 9 ft<sup>3</sup> of material to larger mechanically-rotated bins holding several cubic yards of material.

For composting wastes from marina fish cleaning stations we recommend enclosed static compost bins. These can be constructed from woven wire fencing, discarded wooden pallets, cement blocks or scrap lumber. Treated lumber should not be used since it contains chemical compounds which may be harmful to the microbes in the compost pile. Two examples of static pile compost bins are shown in **Figure 1**.

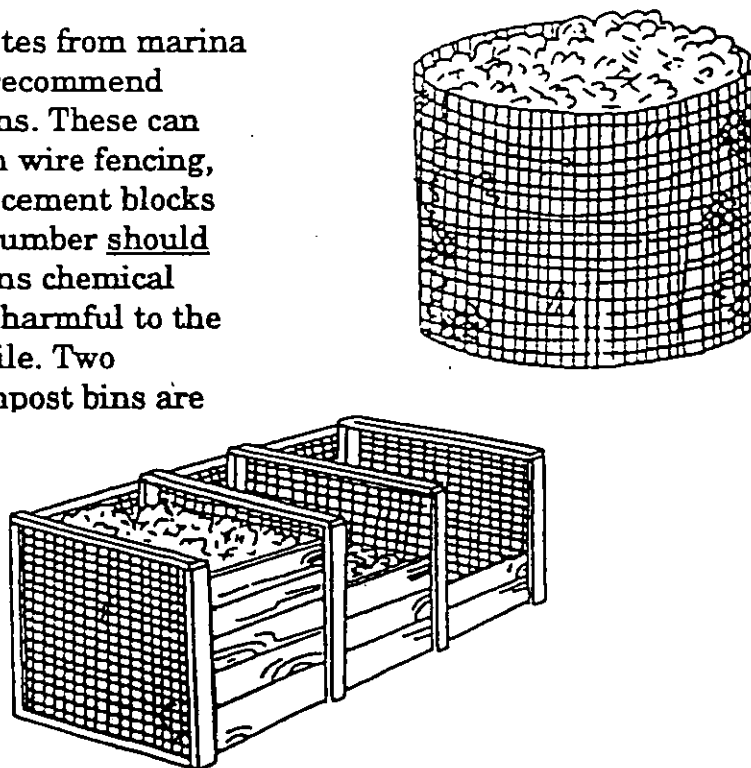


Figure 1. Static pile compost bins.

A three-bin compost system suitable for disposal of fish cleaning wastes is illustrated in **Figures 2 and 3**. This system was successfully used in compost research at Louisiana State University. It is attractive and inexpensive, costing less than \$300 to construct. Each bin holds about 85 ft<sup>3</sup> of compost. A three-bin system is managed as follows: after the first bin is full, begin filling the second bin. By the time the second bin is full, the first bin can be turned by shoveling it over into the third bin. Each pile can be alternately turned in this manner every several days, until compost is complete.

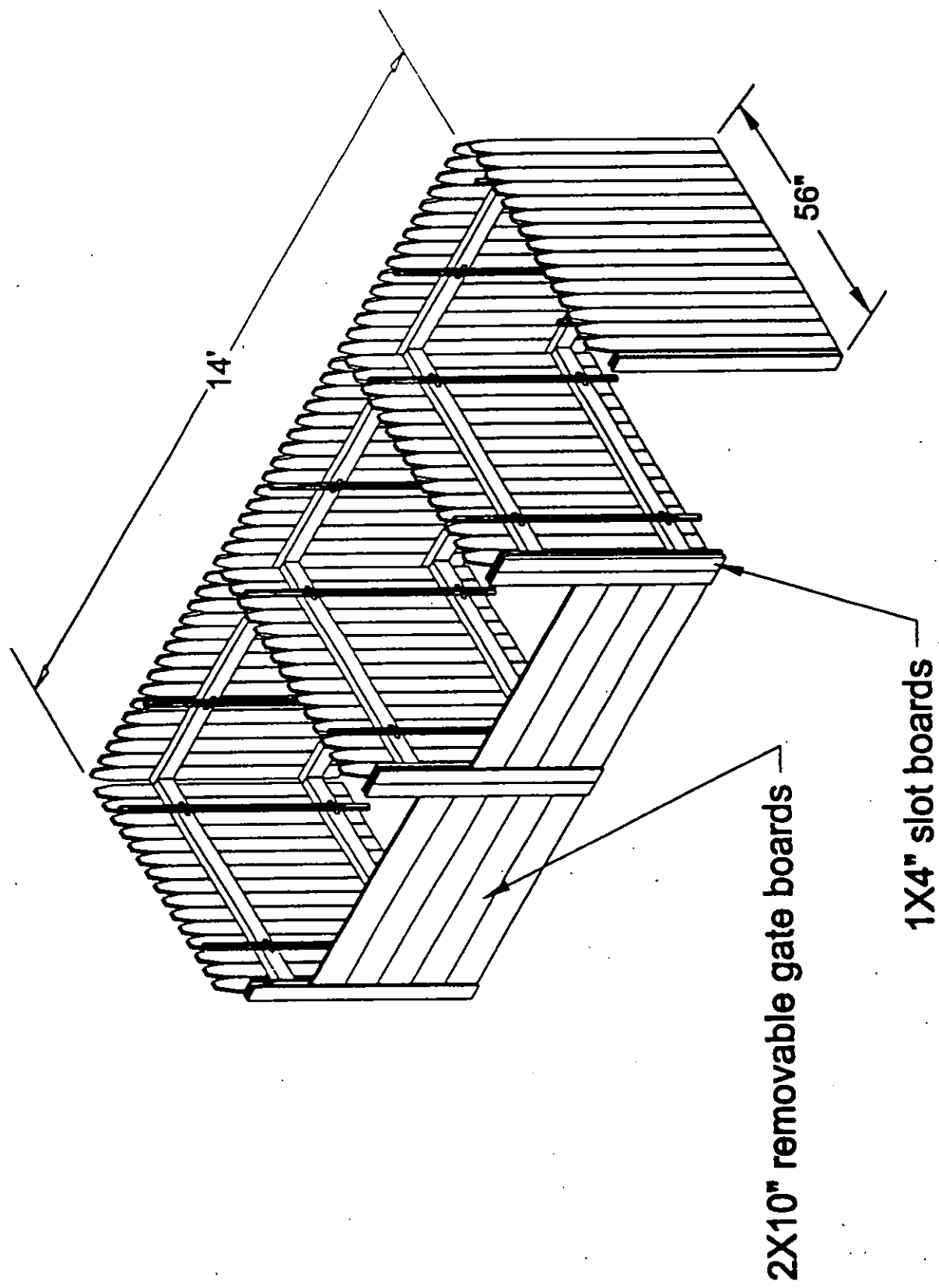
Systems can be made smaller or larger than shown, however, it is not recommended that an individual bin be smaller than 3' x 3' x 3' in size. Smaller piles remain cooler and do not allow the proper internal temperatures to be reached during composting, resulting in incomplete decomposition.

**Constructing The Pile.** In situations where bins are to be filled gradually by adding materials on a daily basis, layering is recommended. The pile is begun by first putting down a 6-8 inch layer of the bulking agent followed by a 6-8 inch layer of fish cleaning wastes (see **Figure 4**). Each layer of fish wastes should be followed by a 2-3 inch layer of bulking agent until the bin is full. The compost should be "capped" by a thick (8-10 inch) layer of bulking agent to prevent odors. When the first bin is full, begin filling the second bin.

Each layer of fish wastes should be no thicker than 6-8 inches. If the layer is too thick the microbes may use up all the oxygen in the layer and anaerobic conditions will develop along with associated putrid odors. Raw fish wastes should not be exposed at any point in the pile or it will attract flies and other animals.

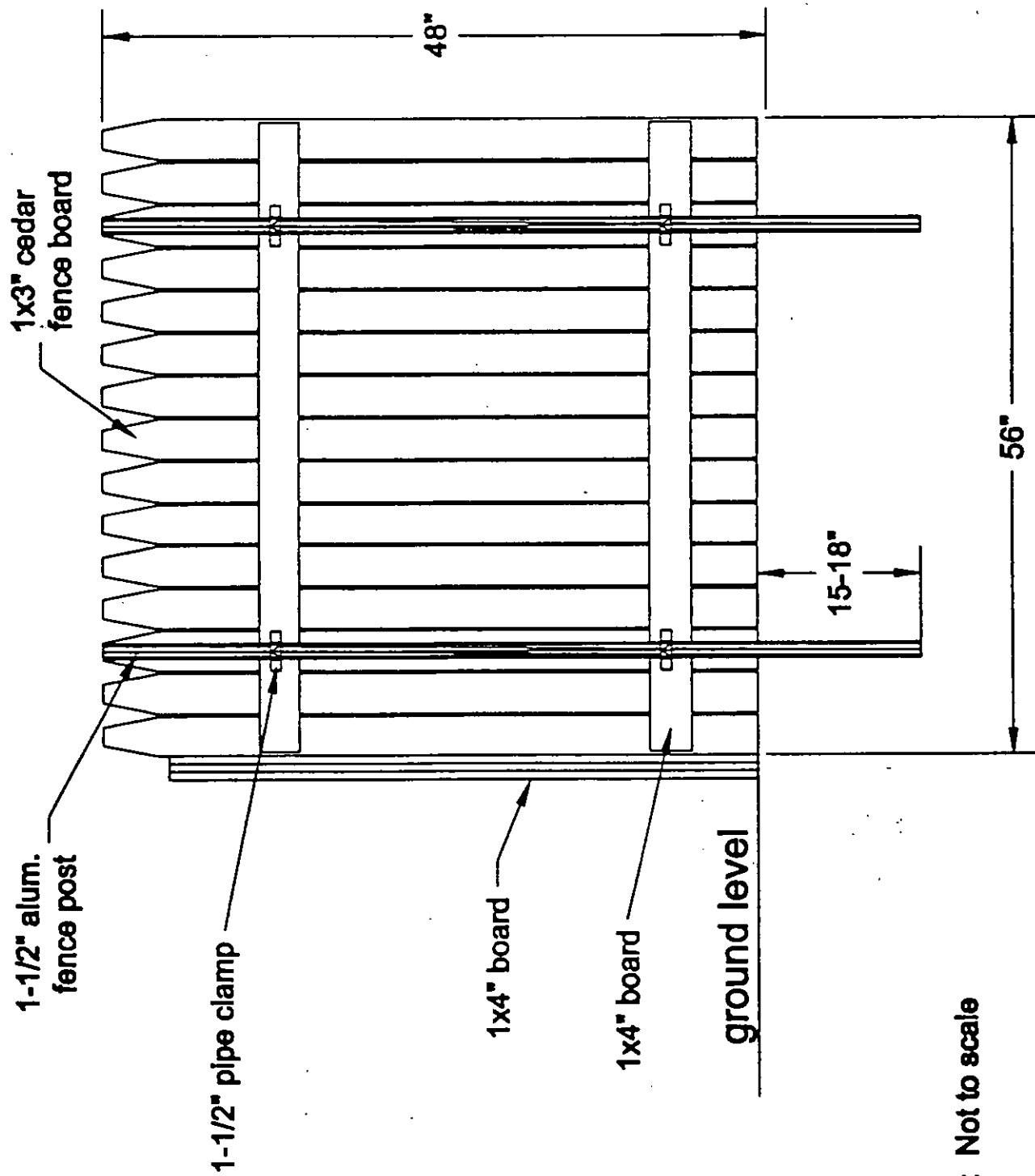
**What Do I Watch For?** The compost process is monitored by observing the daily variation in temperature at the center of the pile. In properly functioning compost, the temperature should rise to 140-160°F within a few days. It will then drop rapidly, signaling that the pile should be turned and aerated. After turning the temperature will again rise rapidly and will then experience a gradual decline to about ambient temperature, at which time the compost process can be considered near complete.

Compost temperature can be monitored by placing a compost thermometer at the center of the pile. Inexpensive thermometers are available at most garden centers for \$10-15.



**Note: Not to Scale**

Figure 2. A three-bin compost system.



**Note: Not to scale**

Figure 3. Detail of compost bin panels.

One should also watch for flies and the development of odors. This can usually be remedied by adding an extra thick layer of bulking agent on the top of the pile.

**Which Bulking Agent Do I Use?** Common bulking agents which are readily available in south Louisiana are bagasse, cotton gin trash, rice hulls, hay and bark. We recommend rice hulls for a number of reasons: 1) they are available most of the year and are inexpensive, 2) they contain a high percentage of silica, which makes their degradation difficult, thus they can be reused and 3) their granular size and shape helps to provide air circulation throughout the compost pile.

**How Do I Calculate The C:N Ratio?** Based on past research experience by Louisiana State University, a mixture of 2-3 parts rice hulls to one part fish cleaning wastes by volume will result in the proper C:N ratio. Use a 30 gallon plastic trash can to measure the materials. Add fresh rice hulls to the mixture only when necessary. Remember, rice hulls decompose slowly, and can be reused.

**Where Do I Locate The Bins?** The compost bins should be located in a convenient, but out-of-the-way location. The compost can be placed either on bare ground, concrete slabs or on a base of shell or gravel. The bins should not be placed close to trees since the roots may spread and grow into the compost. If possible, locate the compost near a source of water so that it can be moistened during periods of drought. If wet weather is experienced for long periods, it may be necessary to cover the compost so that it does not become too wet.

Do not place compost bins too near waterways. If much leachate is produced, this material may leach through the ground into the waterway or wash into the waterway during rainfall episodes. Large amounts of leachate can cause localized oxygen depletion and fish kills.

**How Do I Get Rid Of The Compost?** After the compost is complete, the material can be used in gardens and flower beds as supplement to regular fertilization. Compost should never be considered a complete compost but research has shown that it makes a great soil conditioner or mulch, retains moisture and is a good secondary source of nutrients for plants. Complete compost can also be spread over land. Often, local gardeners can be notified when the compost is complete, and they will offer to haul the material themselves, thus saving the compost operator additional work.

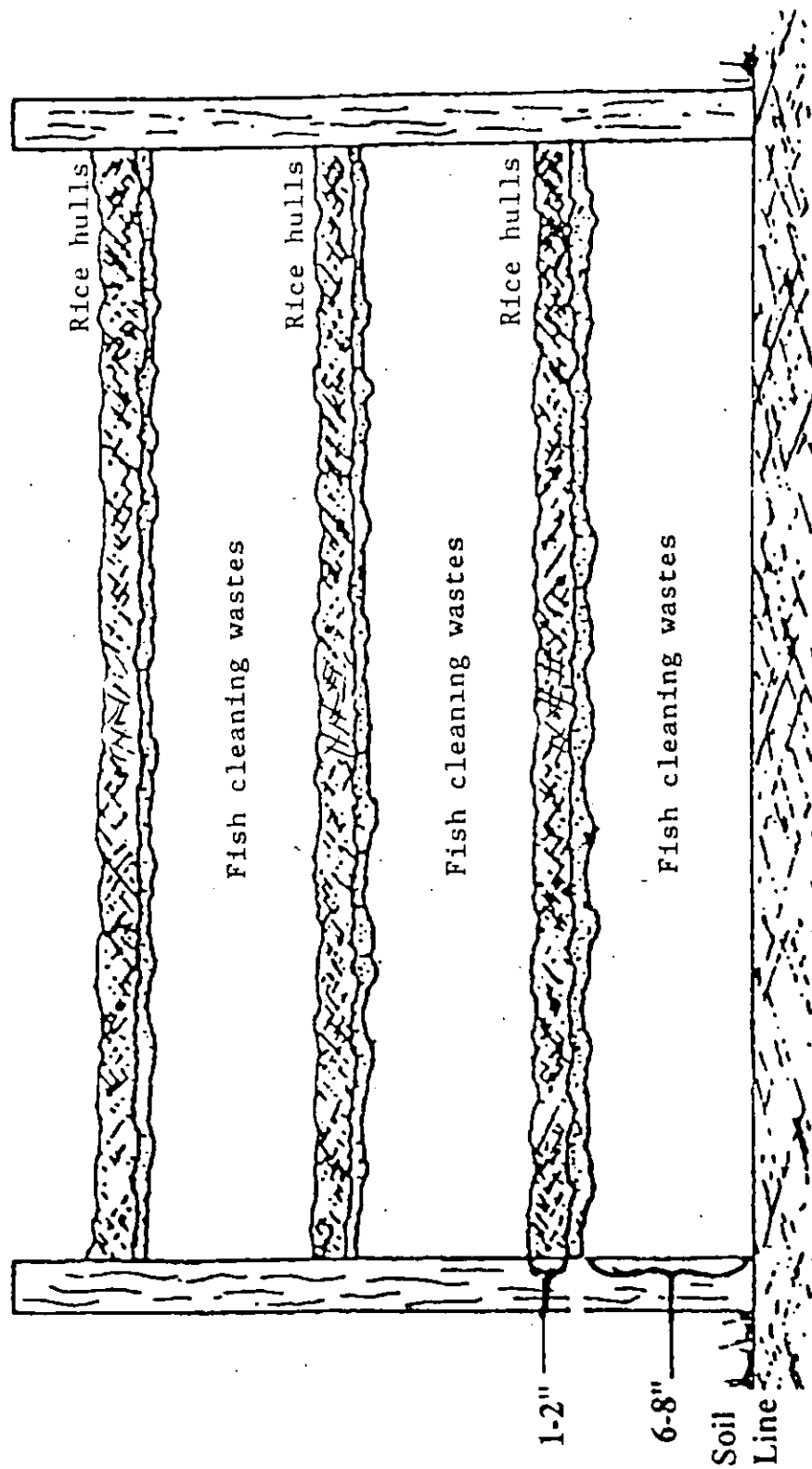
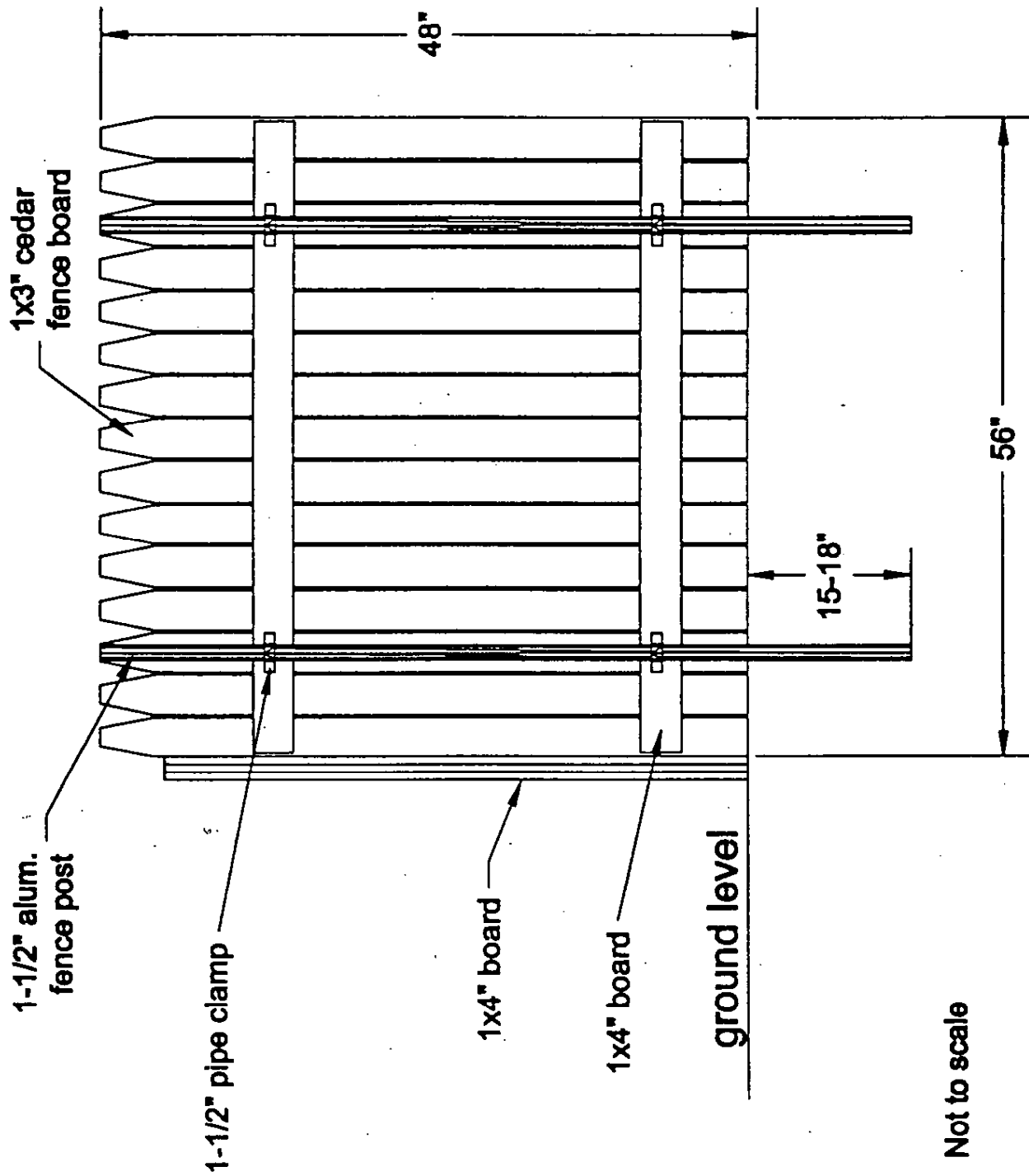
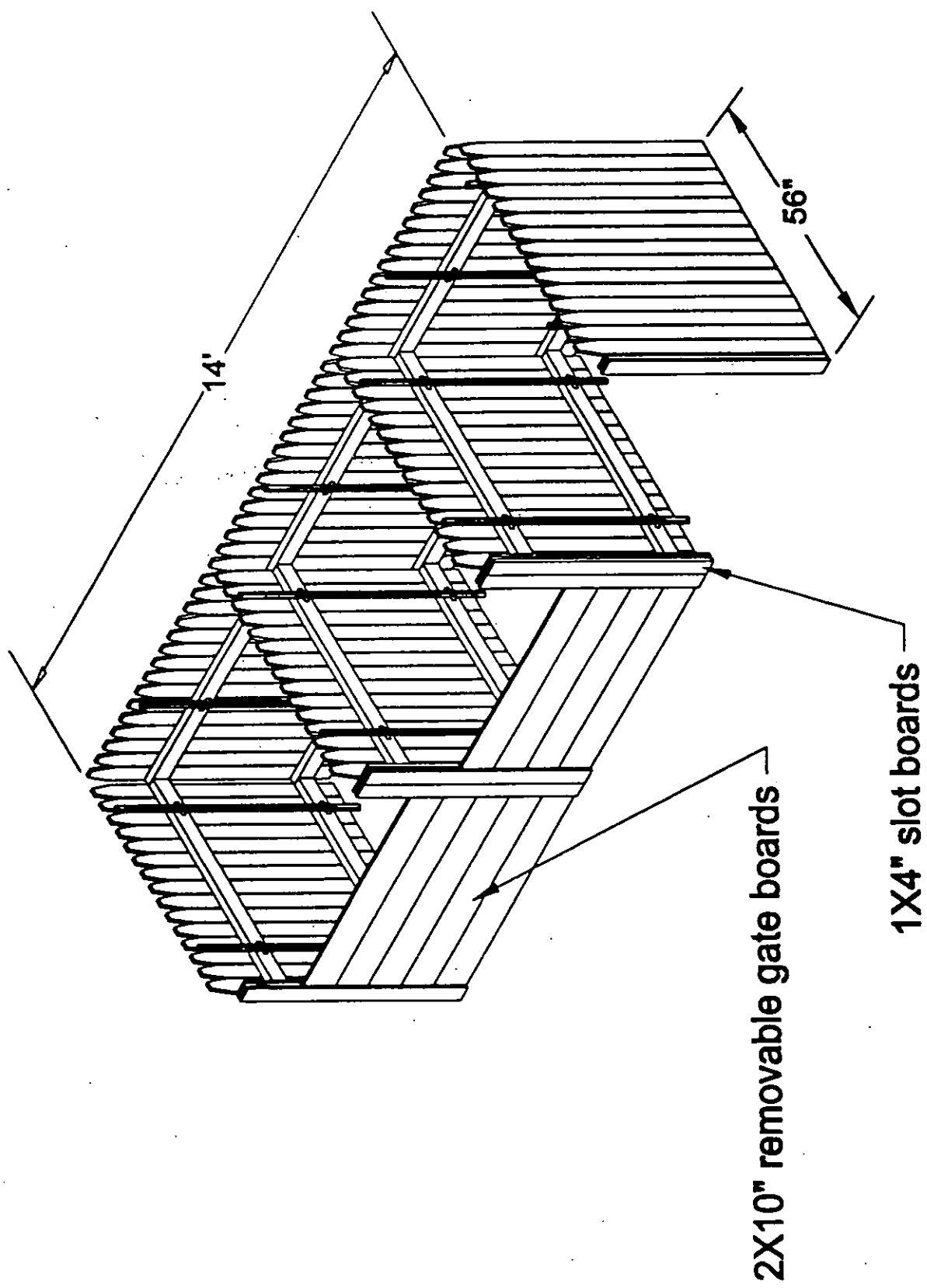


Figure 4: Cross Section of Layering in Compost Bin



Note: Not to scale





**Note: Not to Scale**